Journal

WATER POLLUTION CONTROL FEDERATION

Special Features

1960 Literature Review, Part III—Research Committee Water Pollution

Detergent Frothing—Edwards et al.

Operators' Salaries in Indiana

Sludge Reaeration—Weston

Pittsburgh Plant—Laboon

JULY 1961

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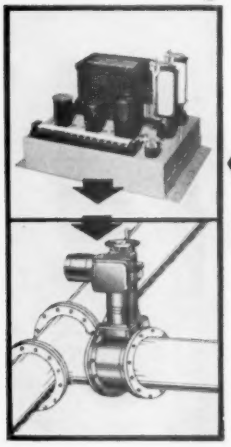

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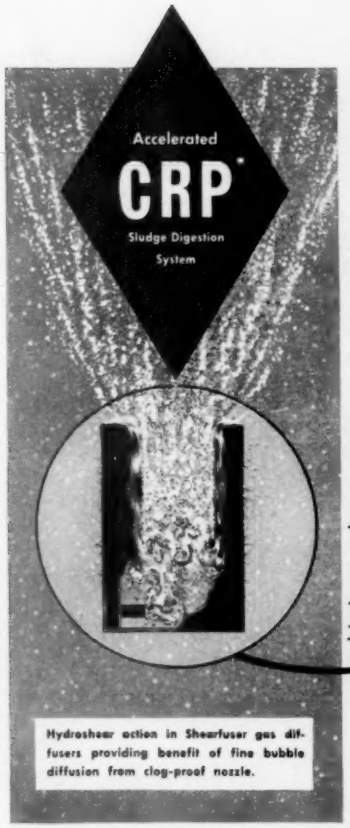

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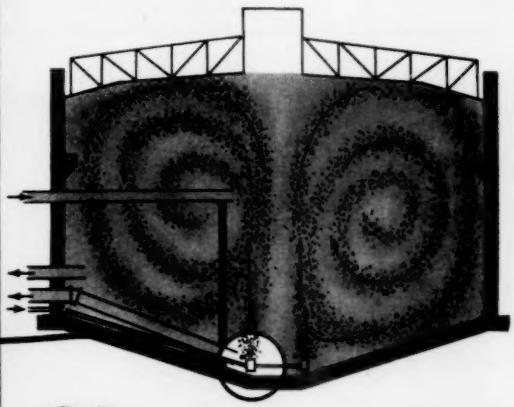

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Volume 33 | July 1961 | Number 7

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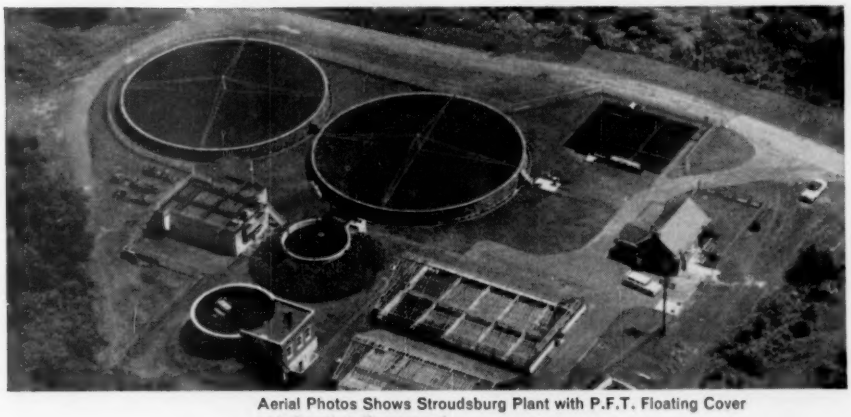

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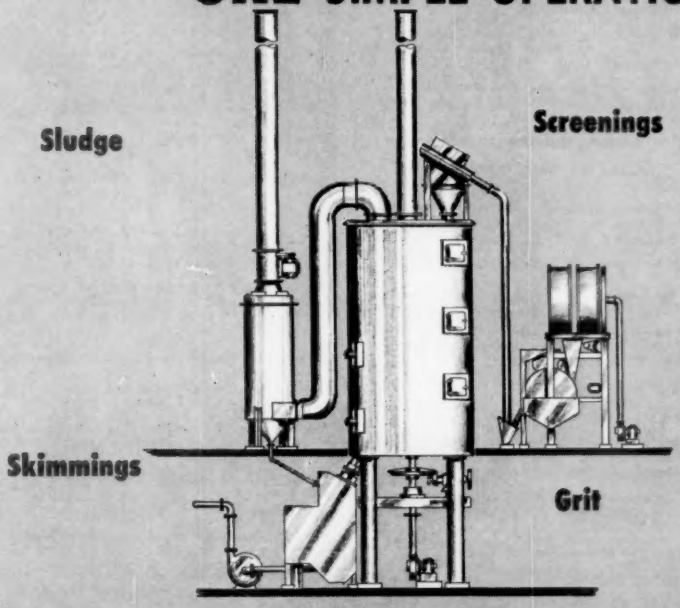

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WATER POLLUTION CONTROL FEDERATION

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MEMBER ASSOCIATIONS MEETINGS

Association *	*Date*	*Place*
Pennsylvania	Aug. 9–11	Pennsylvania State University, State College
New Zealand	Aug. 28–29	Metro. Drain. Bd. Conf. Rm., Auckland, New Zealand
Georgia	Sept. 6–8	Georgia Institute of Technology, Atlanta
Kentucky-Tennessee	Sept. 11–13	Brown Hotel, Louisville, Ky.
Germany	Sept. 12–16	Hamburg, Germany
South Dakota	Sept. 20–22	Sheraton Hotel, Rapid City
Missouri	Oct. 1–3	Kentwood Arms Hotel, Springfield
North Dakota	Oct. 4–6	Gladstone Hotel, Jamestown
Pacific Northwest	Oct. 25–28	Hotel Winthrop, Tacoma, Wash.
Florida	Oct. 29–Nov. 1	Cherry Plaza Hotel, Orlando
New England	Nov. 1–2	Northampton Hotel, Northampton, Mass.
Nebraska	Nov. 8–9	Hotel Lincoln, Lincoln
South Carolina	Nov. 10	Richland County Health Center, Columbia
North Carolina	Nov. 13–15	George Vanderbilt Hotel, Asheville
Indiana	Nov. 15–16	Hotel Washington, Indianapolis
Oklahoma	Nov. 27–Dec. 1	Oklahoma State University, Stillwater

* See preceding left-hand page for full name.

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Milwaukee, Wisconsin

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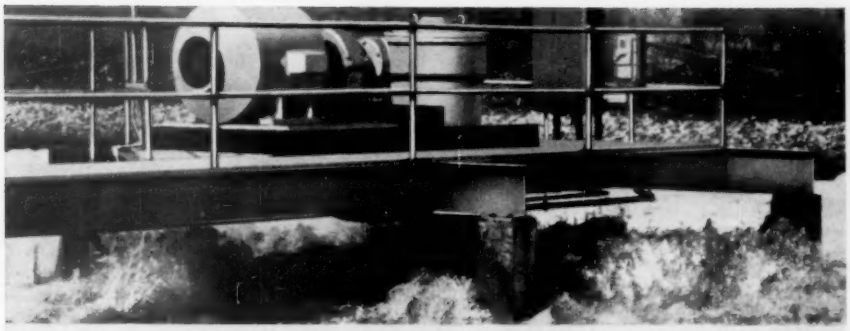
Hotel Headquarters—Schroeder
October 8–12, 1961



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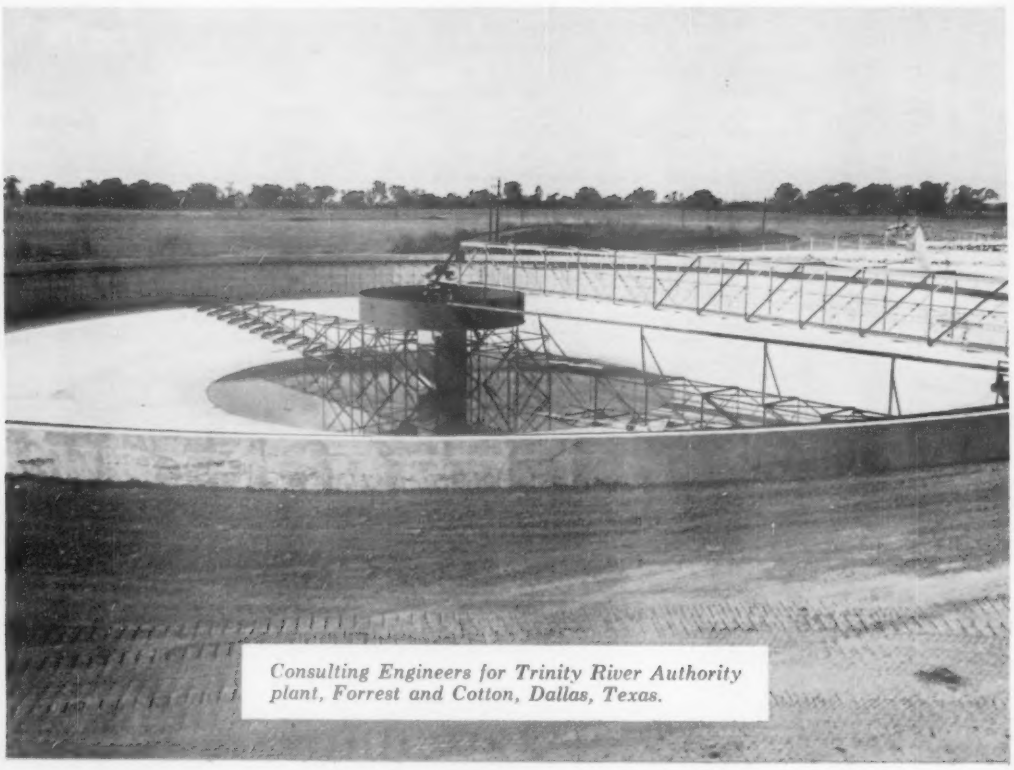

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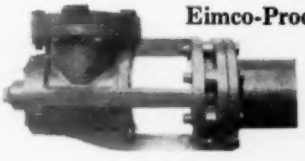

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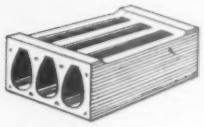

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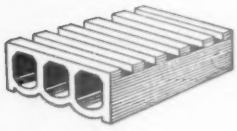

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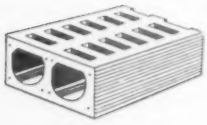
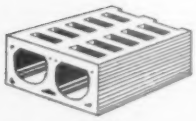
Texas Vitrified Pipe Co.
Mineral Wells, Texas



ARMCRE
Ayer-McCarel Clay Co., Inc.
Brazil, Ind.



BOSCO
Bowerston Shale Co.
Bowerston, Ohio

Trickling Filters have long since earned a high place in engineers' regard by their combination of these 7 advantages:

1. Low cost, initially and in operation
2. Simple easy operation, minimum man-power
3. Long life, outlasting bonds issued
4. Good results. Top notch effluent
5. Reliable performance: many filters built 30 or more years ago still operating satisfactorily.
6. Over-loads are no problem
7. Easy to add to if growth demands.

USE VITRIFIED CLAY UNDERDRAINS

The crowning touch in trickling filter successes is use of TFFI Specification floor blocks. Clay is unsurpassed in resistance to common corrosive factors. These blocks not only serve right, they are made right—in modern plants under manufacturing controls of quality that no substitute material can even approach.

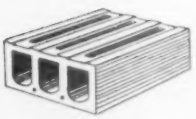
Demand Certified Underdrain Block!

Vitrified Clay Block manufactured by TRICKLING FILTER FLOOR INSTITUTE members and tested by the Materials Testing Laboratory of Rose Polytechnic Institute comply with or exceed ASTM Specification C 159-59T.

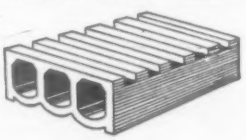
Only TFFI blocks give you a 50-year Guarantee.

TRICKLING FILTER FLOOR INSTITUTE

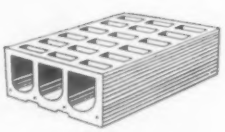
Address nearest member



POMONA
Pomona Terra-Cotta Co.
Pomona, No. Car.



TRANSLOT
Cannelton Sewer Pipe Co.
Cannelton, Ind.



DICKEY
W. S. Dickey Clay Mfg. Co.
Kansas City 6, Mo.

FLUIDICS AT WORK

NOW... ANSWERS TO SOME OF YOUR QUESTIONS ABOUT LIQUID-SOLIDS SEPARATION

New bulletin gives useful facts on dissolved-air flotation unit.

"How can I get a high concentration of solids from a liquid suspension, for re-use or easy waste disposal?"

• • •

"Is there a way to get economical liquid-solid separation, when there are frequent variations in temperature, viscosity, pH, particle size, particle density, and entrainment concentration?"

• • •

"How does the Colloidair Separator keep heat loss to a minimum in the clarified liquid?"

• • •

You'll find answers to these and many other questions in our new Bulletin 4772.

Here, in six pages of facts and illustrations, you have a description of the design and operation of the Permutit Colloidair Separator — the dissolved-air flotation unit that eliminates almost all labor and supervision, and operates automatically and continuously.

If you are interested in this type of liquid-solids separation, we recommend that you study a copy of this bulletin. No obligation. Simply send the coupon below or drop us a note.

THE PERMUTIT CO. a division of Pfaudler Permutit Inc.
50 West 44th St., New York 36, N. Y.

Gentlemen:
I would like information on reducing operating costs and improving liquid-solids separation. Please send me your Bulletin 4772, "Permutit Colloidair Separator."

Name_____

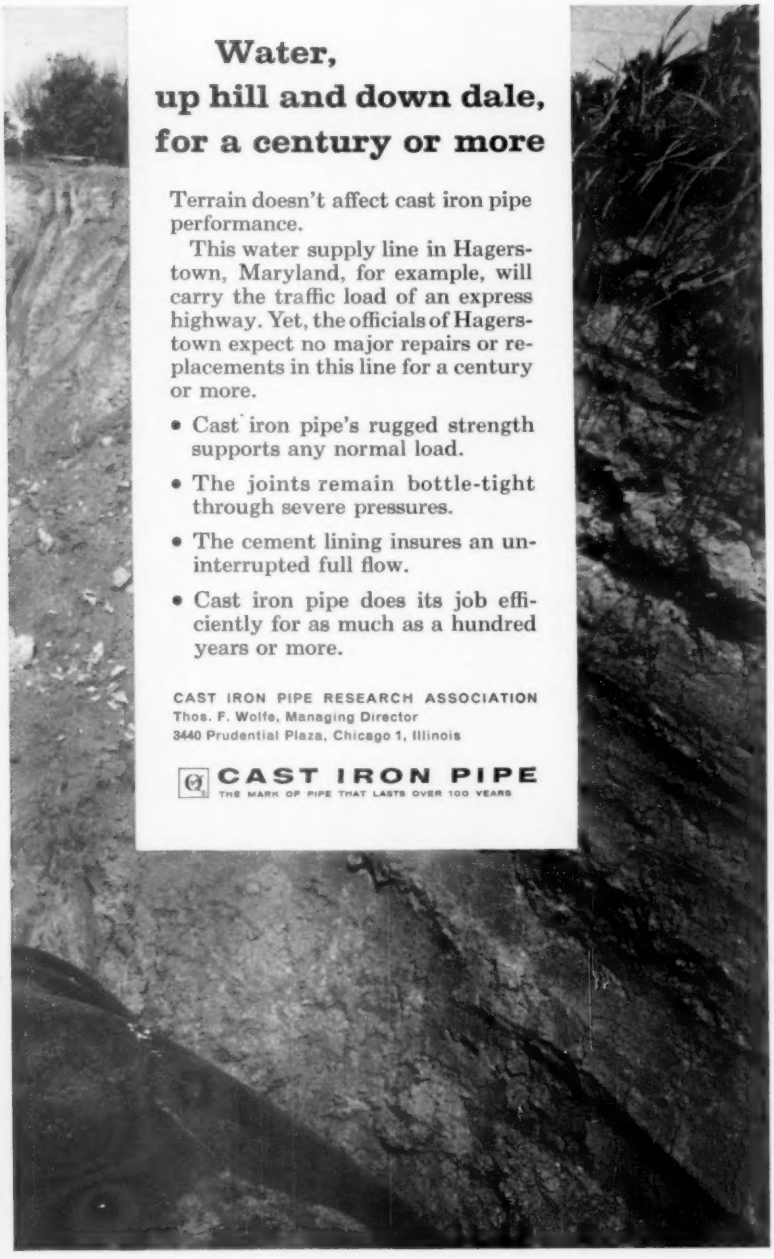
Company or Municipality_____

Title_____

Street_____

City_____ Zone_____ State_____

PFAUDLER PERMUTIT INC.
Specialists in FLUIDICS . . . the science of fluid processes



Water, up hill and down dale, for a century or more

Terrain doesn't affect cast iron pipe performance.

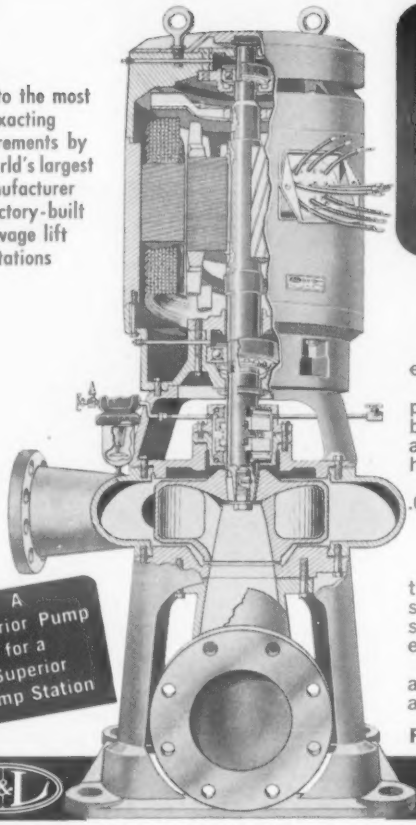
This water supply line in Hagerstown, Maryland, for example, will carry the traffic load of an express highway. Yet, the officials of Hagerstown expect no major repairs or replacements in this line for a century or more.

- Cast iron pipe's rugged strength supports any normal load.
- The joints remain bottle-tight through severe pressures.
- The cement lining insures an uninterrupted full flow.
- Cast iron pipe does its job efficiently for as much as a hundred years or more.

CAST IRON PIPE RESEARCH ASSOCIATION
Thos. F. Wolfe, Managing Director
3440 Prudential Plaza, Chicago 1, Illinois

CAST IRON PIPE
THE MARK OF PIPE THAT LASTS OVER 100 YEARS

Built to the most exacting requirements by the world's largest manufacturer of factory-built sewage lift stations



A Superior Pump for a Superior Pump Station

(2455)

Smith & Loveless
VERTICAL CLOSE-COUPLED "Non-Clog" SEWAGE PUMPS

The One Pump Designed to Meet All the "Must" Requirements for Sewage Service

The Smith & Loveless "Non-Clog" sewage pump is the result of years of experience with over 1,400 varied pump station installations.

The ultimate in design and construction, the "Non-Clog" pump is precision manufactured of superior materials—with over-size shaft and bearings. Special attention is given to corrosion and abrasion resistance and ease of maintenance. Maximum pump efficiencies with ability to handle 3" solids.

The pump is designed with close tolerances: shaft runout is held to .003", shaft end play to .010" and vibration movement to .005".

The Advantages of the Mechanical Seal . . .

The sewage lift station field experience of Smith & Loveless has proved the advantages of "dead tight" mechanical seals. The double mechanical seal system in the Smith & Loveless "Non-Clog" sewage pump is the most satisfactory way to prevent sewage, noxious and dangerous gases from entering the pump room.

Mating surfaces of the long-wearing carbon and diamond-hard ceramics are lapped to a flatness tolerance of one light band to insure a liquid and gas-tight seal.

For further information, write for new Bulletin 500-A. Address: Dept. 30

S&L Smith & Loveless

DIVISION UNION TANK CAR COMPANY
P. O. BOX 8884
KANSAS CITY 15, MISSOURI
Plant: Lenexa, Kansas

The Clay Pipe Industry's research has pioneered dramatic new developments, making production and installation of lifetime Vitrified Clay Pipe more efficient and effective.

For example, Clay Pipe Industry research discovered the revolutionary resilient compression joints which are now offering important savings in installation time and cost to users of lifetime Vitrified Clay Pipe sanitary sewers.

Other important tests are now going on at the Crystal Lake facility, by contract at colleges and universities all over the country, and at the modern laboratories maintained by individual Clay Pipe manufacturers.

One experiment that promises to have far-reaching effects: detailed, year-long observations of root penetration of 16 separate sewer pipe joints. Others include shear load studies of both pipe material and joints, development of new, less expensive jointing materials and techniques, exhaustive analyses of competitive products, flow-coefficient studies, and various tests aimed at improving the clay pipe itself.

Results of the most significant of these tests will be announced as they become available.

Under the direction of A. J. Reed, NCPMI Vice President and Director of Research, new breakthroughs in manufacturing and uses of Clay Pipe are being made, offering greater, more confident service to those who specify and use lifetime Vitrified Clay Pipe.

NATIONAL CLAY PIPE MANUFACTURERS, INC., *Washington, D.C.*

COMPRESSION SEALED, VITRIFIED
CLAY PIPE
IMPERVIOUS
THE STANDARD in SANITARY SEWERS

NATIONAL CLAY PIPE MANUFACTURERS, INC.
914 20th Street, N. W.
Washington, D. C.

Please send me full details on the new factory-made compression joints on Clay Pipe.

(name)

(company)

(street address)

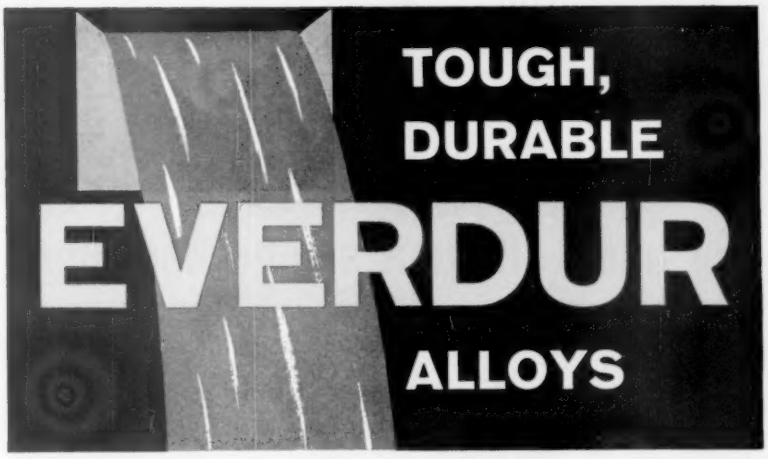
(city and state) 8-11 WP

One ounce in 63 lbs. isn't much, but the Merchen Feeder is so sensitive it quickly responds to even this tiny change. That's why the Merchen gives you the kind of accuracy you need. You get precision feeding of any dry, free-flowing material.

The secret's in a split-deck weighing platform. The Merchen weighs nothing but the actual material passing over the platform. Feeder components are never weighed . . . can't confuse accuracy.

Couple this accuracy with the Merchen's range of up to 1000:1; its rigid, vibration-free construction; above all, its compact size. You'll find the Wallace & Tiernan Merchen Feeder fits your treatment plant exactly . . . gives you hour-to-hour accuracy for more economical dry feeding. Write for information. Dept. M-62.84.

WALLACE & TIERNAN INC.
25 MAIN STREET, BELLEVILLE 9, NEW JERSEY



highly resistant to wear and abrasion in sewage and water works systems

EVERDUR® copper-silicon alloys have excellent resistance to corrosion in all types of water works installations and at all stages of sewage treatment operations. EVERDUR equipment in the United States has been in service *without replacement* for 30 years and longer.

Easily fabricated EVERDUR provides high physical strength with lighter weight. It is used extensively in sewage systems handling corrosive wastes in screens, stems, manhole steps, guides, bolts, weirs, float chambers, troughs. And for water works equipment you will find EVERDUR alloys in long service as surface reservoir outlet screens and screen frames and as large diameter cylindrical well screens in drilled well supply systems. Other uses: spillway fittings, guides, seats and sealing strips. And don't forget EVERDUR Electrical Conduit for use in corrosive atmospheres.

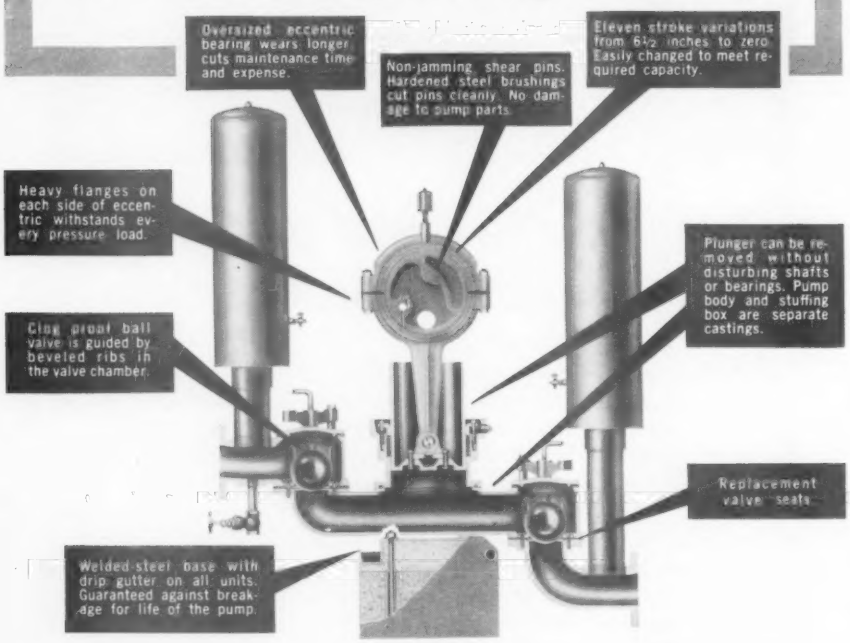
Publication E-11 shows typical applications and other data. Write for your copy—or for assistance from our Metallurgical Dept. in selecting the proper corrosion-resistant alloys for your equipment. Address: Anaconda American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Canada. 61-811

EVERDUR®
a product of
ANACONDA®
AMERICAN BRASS COMPANY

LOOK AT THE ADVANTAGES

you get with *Marlow* plunger pumps

for more efficient sludge handling!


Oversized eccentric bearing wears longer, cuts maintenance time and expense.
Non-jamming shear pins. Hardened steel brushings cut pins cleanly. No damage to pump parts.
Eleven stroke variations from 6½ inches to zero. Easily changed to meet required capacity.
Heavy flanges on each side of eccentric withstands every pressure load.
Plunger can be removed without disturbing shafts or bearings. Pump body and stuffing box are separate castings.
Clog proof ball valve is guided by beveled ribs in the valve chamber.
Replacement valve seats
Welded steel base with drip gutter on all units. Guaranteed against breakage for life of the pump.

PLUS...

1. Constant out-put despite changing head conditions.
2. High pressures when needed to free clogged lines.
3. Self priming . . . no auxiliary priming equipment required.
4. Rugged construction . . . stones, metal slugs can not harm pump parts.

find out how Marlow Plunger Pumps can solve your sludge handling problem. Start now by writing for catalog W-59 and complete information.

Marlow PUMPS

MARLOW PUMPS

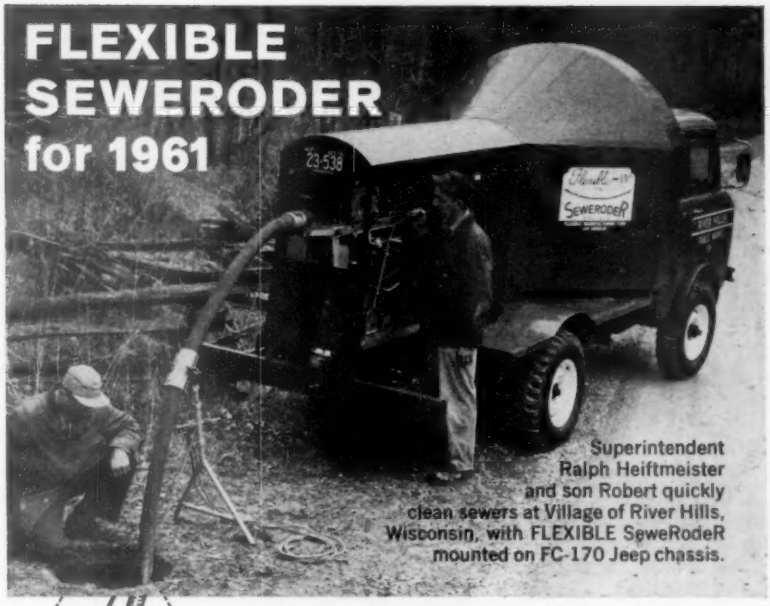
Division of Bell & Gossett Company

MIDLAND PARK, NEW JERSEY

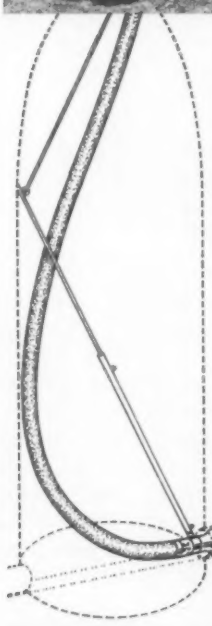
Longview, Texas • Morton Grove, Illinois

O-567

FLEXIBLE SEWERODER for 1961



Superintendent Ralph Heiftmeister and son Robert quickly clean sewers at Village of River Hills, Wisconsin, with FLEXIBLE SeweRodeR mounted on FC-170 Jeep chassis.



Now This Village Can Whip Any Sewer Emergency – FAST!

With a population of 1257 and 20 miles of sewer to maintain, the Village of River Hills solved its problems with existing manpower. They chose the Flexible '61 SeweRodeR and have tripled cleaning capacity for preventive maintenance: the crew can clear a stoppage anywhere along the entire 20-mile sewer system in 30 minutes. Village, town or city– "Flexible" has the equipment to solve any sewer cleaning problem FAST and economically.

Contact your Flexible Sales Engineer today.

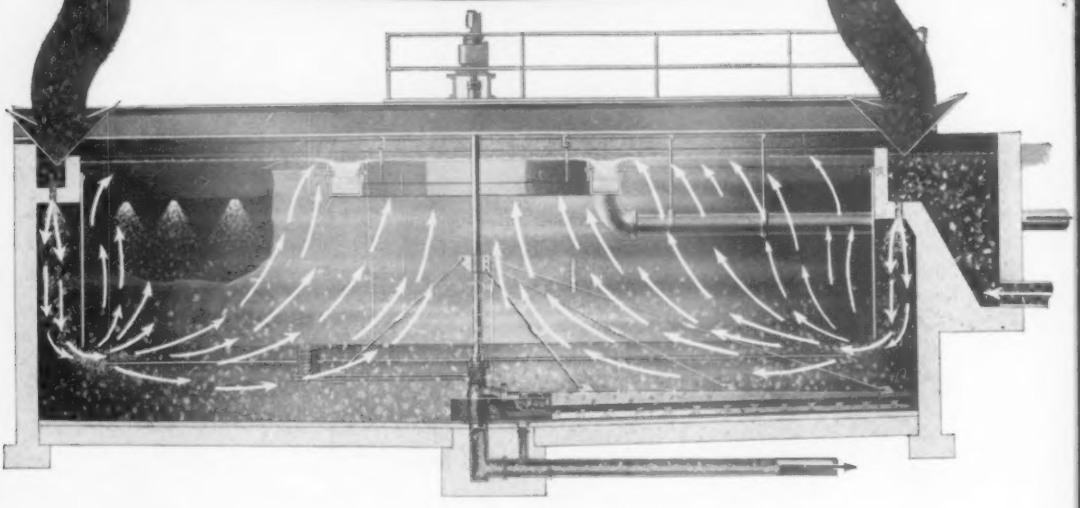
1961 FEATURES:

- Now more positive rod drive for smoother operation
- Economical 48" rods • 900 ft. reel capacity
- 4 to 4,000 lbs. controllable push-pull power
- Instantly reversible.

FLEXIBLE, Inc.

415 SOUTH ZANGS BLVD., DALLAS, TEXAS
3786 DURANGO AVE., LOS ANGELES 34, CALIF. • 1005 SPENCERVILLE ROAD, LIMA, OHIO

Feed outside-in...



to DOUBLE clarifier capacity

That's the capacity-adding difference between the exclusive Rex Rim-Flo Clarifier and conventional circular center-feed tanks. In Rim-Flo, the flow is introduced into a feed channel around the enitre periphery of the tank. The feed channel is hydraulically sized to provide uniform velocity of flow and to prevent depositing of solids in the channel bottom. The flow is then uniformly introduced into the tank through properly sized and spaced orifices in the channel bottom...each orifice taking its proper share of the total flow.

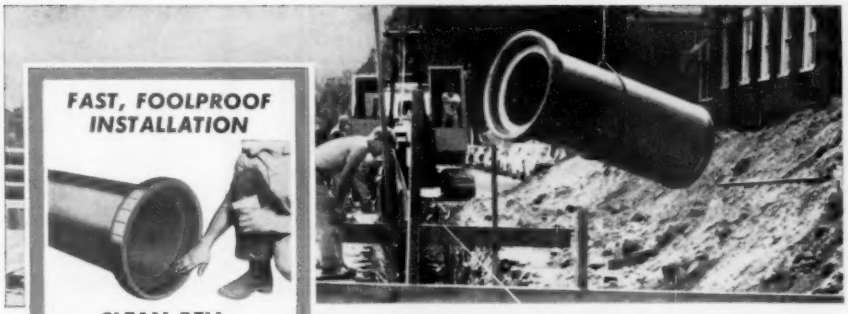
The influent entering the tank is distributed evenly between the outer tank wall and the baffle skirt. This area serves to reduce the effect of discharge through the ports so that the flow approaching the tank bottom is well diffused and at lowest possible velocity.

Because of this thorough diffusion and low velocity, harmful eddy currents and short-circuiting are practically eliminated. The flow moves gently throughout the entire tank cross section utilizing virtually the entire tank volume. Flow is directed upward to the center of a central effluent trough.

This proven principle will handle at least double the flow of a conventional tank...provide maximum efficiency. Why not get all the facts today. Write CHAIN Belt Company, 4606 W. Greenfield Ave., Milwaukee 1, Wis.

REX®

CHAIN BELT COMPANY



FAST, FOOLPROOF INSTALLATION

CLEAN BELL

CLEAN SPIGOT

PLACE RUBBER "O" RING IN SPIGOT GROOVE

LINE UP, SHOVE INTO PLACE THAT'S ALL THERE IS TO IT!

TODAY'S

FAST, TIGHT, TOUGH FACTORY-MADE JOINT

Wedge-Lock* Type "O"

BY ROBINSON

Now Available In Diameters Through 36"

Now, lines go in faster, seal tighter, stay trouble-free longer. Robinson Type "O" joints reduce laying time . . . cut installation costs . . . are ideally suited to difficult installation conditions. New precision-tight Factory-Made Wedge-Lock Type "O" joints handle infiltration and roots in any terrain.

THE ROBINSON CLAY PRODUCT CO.
ESTABLISHED 1856
AKRON 9, OHIO

*Patented. T.M. Reg. U.S. Pat. Off.

FASTER SERVICE

You get quick delivery of all sizes from strategically located Robinson branches.

FOR MORE DETAILS

on Robinson Factory-Jointed Clay Pipe, Call the Robinson Branch Office nearest you.

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BALTIMORE 2, MD.
1546 Mathieson Bldg. MUlberry 5-2930

BOSTON 34, MASS.
22 Pratt St., Allston Station STadium 2-8900

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1146 Seneca St. TRiangle 3082

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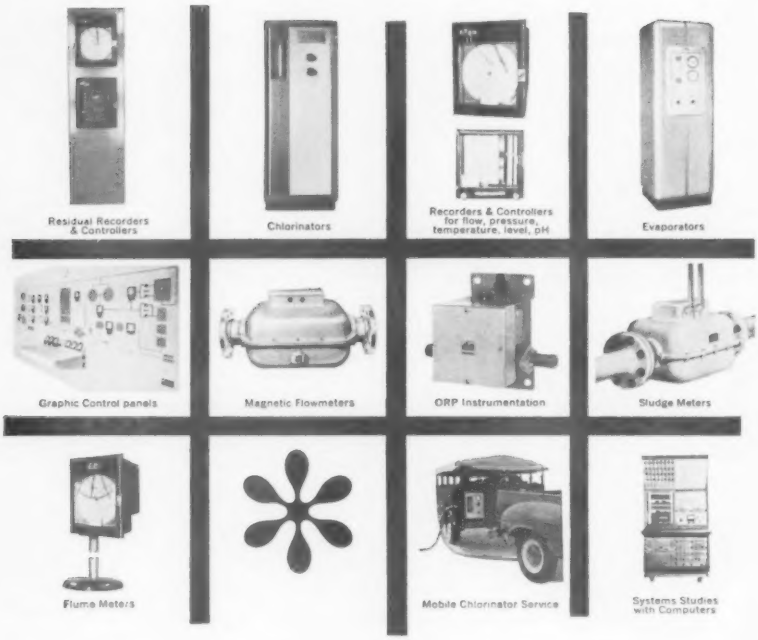
Baldwin Ave., Concord, Ontario, Canada AVenue 5-1138

YONKERS, Westchester County, N. Y.
1013 Saw Mill River Road YOnkers 8-7762



*For Automation of Waste Treatment . . .

Complete Instrumentation and Chlorination Equipment

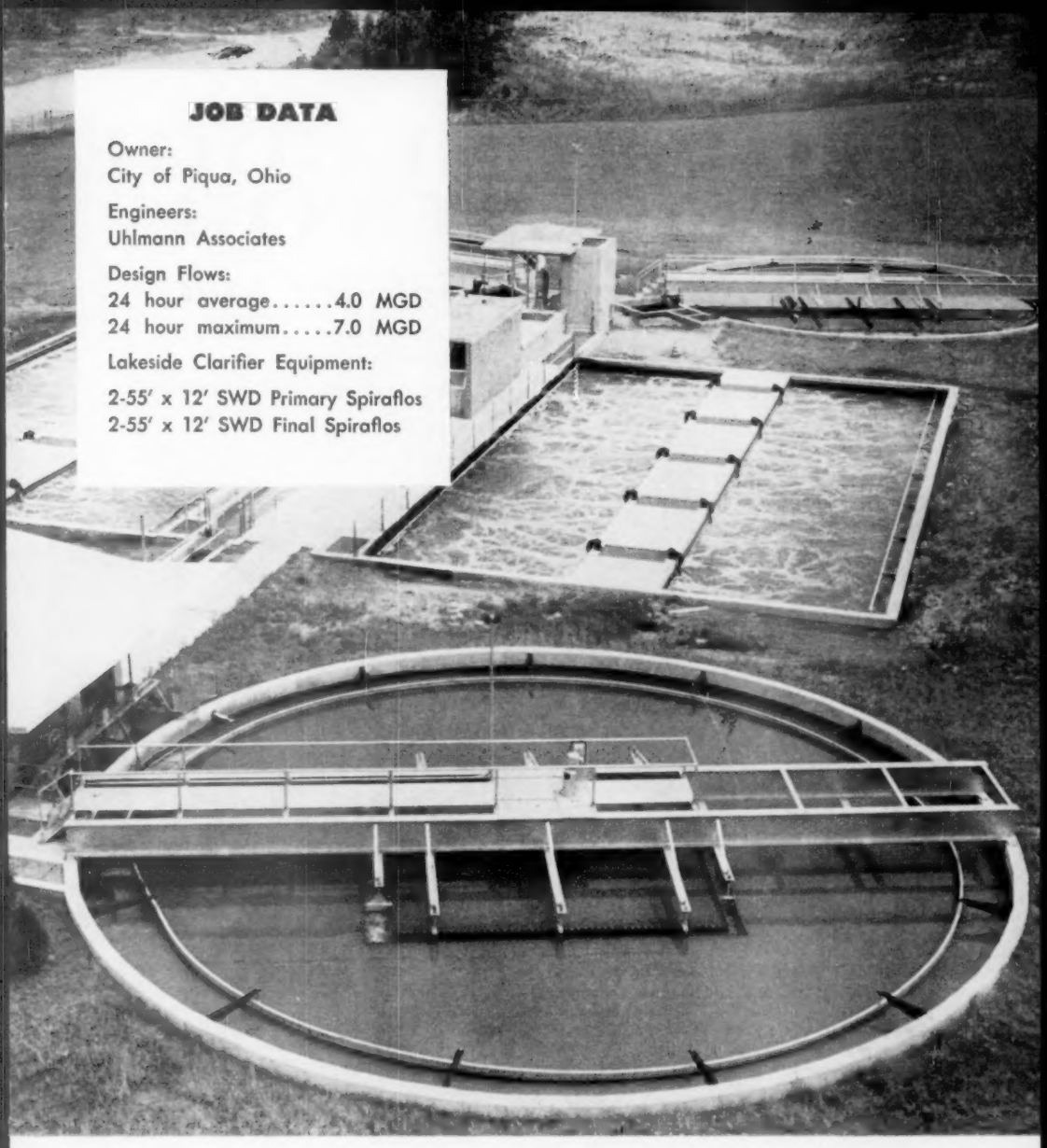
Why shop around for system components? Save time and money as you design automation for your waste treating plant—and gain years of trouble-free service after installation—with F&P instrumentation and chlorination systems. Flowmeters, recorders, controllers and chemical treatment equipment can all be selected as a coordinated system—from a single, reliable source! And the unusually wide F&P selection means we can recommend without prejudice.

For basic information or specific suggestions, write Fischer & Porter Co., 1171 Fischer Road, Warminster, Pa. In Canada, write Fischer & Porter (Canada) Ltd., 2700 Jane Street, Toronto.

FP

FISCHER & PORTER COMPANY

CHLORINATION AND INSTRUMENTATION



JOB DATA

Owner:
City of Piqua, Ohio

Engineers:
Uhlmann Associates

Design Flows:
24 hour average.....4.0 MGD
24 hour maximum.....7.0 MGD

Lakeside Clarifier Equipment:

2-55′ x 12′ SWD Primary Spiraflos
2-55′ x 12′ SWD Final Spiraflos

SPIRAFLOS—give high removals as both primary and final settling tanks—ideal as finals on activated sludge because of the added depth and the flow pattern that traps the light activated particles in the sludge blanket build up. Also a perfect clarifier for the smaller plants particularly where efficient skimming and scum removal are desired.

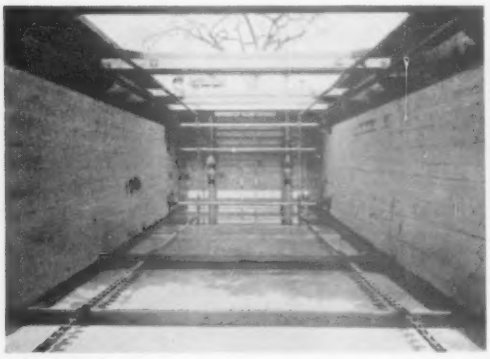
LAKESIDE
ENGINEERING CORPORATION
222 West Adams St., Chicago 6, Illinois

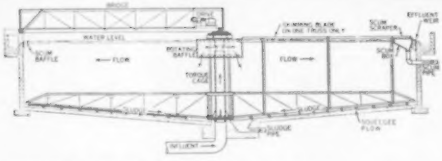
WHICH SLUDGE COLLECTOR

can do the best job for you?

For maximum efficiency . . .
minimum disturbance of flow . . .
choose LINK-BELT
STRAIGHTLINE sludge collectors

For large installations
where construction economies
are vital . . . it's LINK-BELT
CIRCULINE sludge collectors





STRAIGHTLINE COLLECTORS are scraper conveyors made in various styles to handle sludge and scum in *rectangular tanks*. Straightline design means the shortest possible travel for the collected material. It also permits a steady slow speed of the collecting flights that is uniform over the entire floor surface of the tank. This results in maximum efficiency with minimum disturbance to the flow. Straightline collectors can also be installed in the Link-Belt Uniflow settling tank—an improved rectangular design combining a rapidly sloping bottom with a system of multiple effluent weirs.

Send for Straightline Sludge Collector Book 2746 and Uniflow Settling Tank Book 2648

CIRCULINE COLLECTORS are installed in either rectangular or round tanks. Link-Belt offers four series—R, S, T and C. Series R are usually installed in circular tanks and are used to remove settled sludge from the tank floor and scum from surface of liquid. Series S are for square tanks, or rectangular tanks where sludge is collected only from the influent end of tank. Series T are similar to Series R, except they are built to withstand torques encountered in removing heavy settled solids. Series C have both the economical feature of circular tank construction and the positive sludge and scum collection of a straightline sludge collector.

Send for Circaline Sludge Collector Book 2546

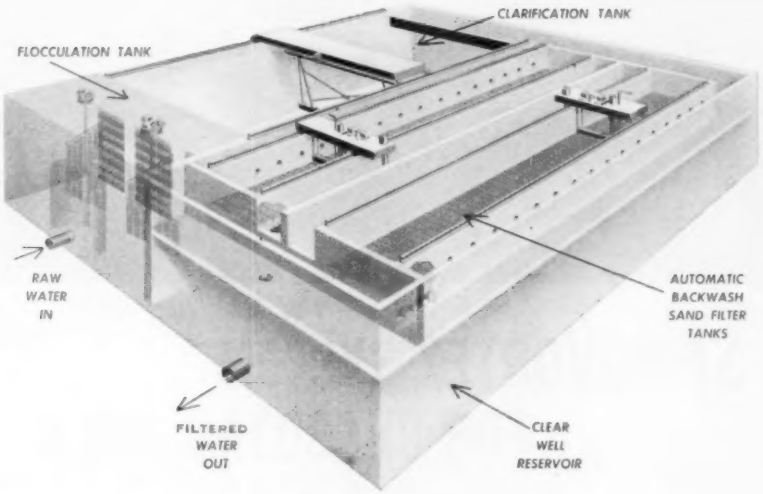
LINK-BELT

SANITARY ENGINEERING EQUIPMENT

15.631

LINK-BELT COMPANY: Executive Offices, Prudential Plaza, Chicago 1. Sanitary Engineering Regional Office—Atlanta, Chicago 9, Colmar, Pa., Kansas City 8, Mo., San Francisco 24. District Sales Offices in All Principal Cities. Export Office, New York 7. Representatives Throughout the World.

NEW *"Unitized"* HARDINGE WATER-TREATMENT SYSTEM



- **FLEXIBLE**
- **FUNCTIONAL**

The practical design for water treatment, which incorporates the safe and established methods for controlled flocculation, sedimentation, rapid sand filtration and storage—all in one, compact system, sized to your requirements.

With the Hardinge system, initial savings are realized in design, materials and construction. Operating economies are effected in power requirements and plant supervision.

Write for further information, giving us the details of your water problem.

HARDINGE
COMPANY, INCORPORATED
Main Office and Works • 240 Arch St., York, Pa.

"Hardinge Equipment—Built Better to Last Longer."

NEW YORK
TORONTO
CHICAGO
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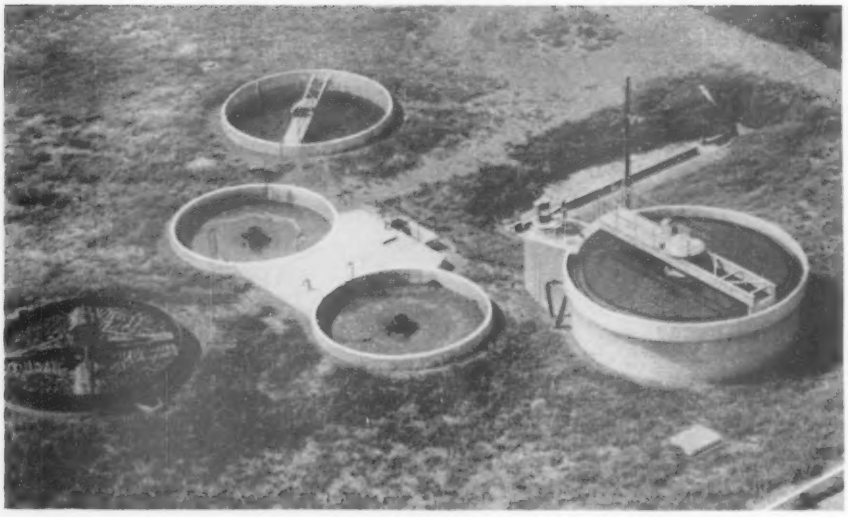
SALT LAKE CITY
SAN FRANCISCO
HOUSTON
LAKELAND
BIRMINGHAM



SPIROVORTEX SYSTEM FOR CHECOTAH, OKLA.

Another new development in Activated Sludge Treatment

The sewage treatment plant shown above was placed in operation last year to serve a population of 3,500 in a recreational and agricultural area. It utilizes the Dorr-Oliver SpiroVortex System, providing B.O.D. removal in excess of 90% with low overall operating costs, simple control and capability for effective handling of widely varying loads.

Units comprise a 30′ dia. Dorr Clarigester, two 24′ dia. SpiroVortex tanks providing rapid and thorough mixing by a spiraling action, one 26′ dia. Superate Filter giving highly efficient aeration and filtering, and a 24′ dia. Dorr Final Clarifier.

For information on the operation of the SpiroVortex System, write for Bulletin 7314 to Dorr-Oliver Incorporated, Stamford, Connecticut.

Consulting Engineers: Collins & Flood, McAlester, Okla. and Ardmore, Okla.
General Contractor: Bell Construction Company, Okmulgee, Okla.

Clarigester, SpiroVortex, Superate T.M. Reg. U.S. Pat. Off.

DORR-OLIVER

WORLD-WIDE RESEARCH • ENGINEERING • EQUIPMENT

A REVIEW OF THE LITERATURE OF 1960 ON WASTEWATER AND WATER POLLUTION CONTROL

H. Heukelekian, Chairman, R. M. Manganelli, Vice-Chairman, T. A. Alspaugh, E. J. Berg, H. F. Clark, C. H. Connell, W. E. Dobbins, G. P. Edwards, M. B. Ettinger, D. G. Foulke, T. deS. Furman, P. E. Gaffney, I. Gellman, H. G. Harding, J. D. Helwig, R. D. Hoak, R. S. Ingols, W. M. Ingram, P. W. Kabler, M. Katz, F. W. Kittrell, N. J. Lardieri, H. G. Luley, P. H. McGauhey, R. Porges, A. J. Steffen, C. Straub, C. M. Tarzwell, G. H. Teletzke, W. W. Towne, H. A. Trebler, E. C. Tsivoglou, E. Weisberg, and R. L. Woodward

WATER POLLUTION

Biology

Pollution Surveys and Investigations

A series of surveys were made on the Japanese coastal waters from 1954 to 1959. These studies were aimed at determining the effect of pollution on the benthic communities. The first area investigated was the Fukuyama Inlet (115) where the water is highly polluted, especially in the inner region. The establishment of communities appeared to be well correlated with the bottom conditions. *Notomastus* sp., *Polydora* sp., and *Stenothyra edogawaensis* were of the dominant numbers in the region where the bottom mud was polluted. An investigation of the Mihara Bay (116) revealed low DO in water of the inner region of the north canal and that pollution in the bottom soil was much higher in the spring. The relationship between soil grades and its ignition loss showed no definite seasonal change in the various stations' samples. However, the stations having larger ignition losses and higher humus content than the others alter seasonally. Poor bottom fauna were found in the polluted areas and these consisted entirely of *Polychaeta* and *Notomastus* sp. The biological results of the Osaka Bay area (117) were the same as those in the Mihara Bay. The relationship between soil grades and ignition losses showed seasonal changes, namely, ignition loss was lower in August than in March at every sampling station. However, the area with no bottom fauna was the largest in August because of the low DO in the bottom layer of water. A survey of 26 stations on the Kanzaki River (118) also showed a seasonal relationship be-

The authors comprise the Research Committee of the Water Pollution Control Federation.

This last of three sections of the Literature Review covers water pollution. The first section, dealing with analytical methods and sewage, was published in the May 1961 issue of THIS JOURNAL. *The second section, on industrial wastes (including radioactivity), appeared in the June 1961 issue of* THIS JOURNAL.

tween soil grades and ignition losses. A survey of Hiro Bay (119) was chiefly concerned with the study of Polychaetous annelids. The Bay was divided into areas; a very polluted bottom area in which there was no animal life, a polluted bottom area with *Capitella capitata Japonica* predominating, a semi-healthy bottom area with *Nebalia bipes* and *Brachidontes senhousia* predominating, and a healthy bottom area characterized by a large number of species of bottom fauna with *Lumbriconeries impatiens* predominating.

From 1951 to 1954 surveys were made of the Thames Estuary (72). In the course of these surveys it soon became clear that the DO content of the estuary water was influenced by numerous factors, some physical and others chemical or biochemical in nature. Some observations were made both of numbers and species of algae present. Diatoms and green algae (mainly Chlorococcales) constituted almost the whole population at each station in most weeks. Green algae appeared in quantity only in water of low salinity. Diatoms were the most important algae in the marine phytoplankton. Quantitatively, the effect of pollution was to produce much larger populations than are usually found in the sea, but at the same time the population was reduced as compared with the productive fresh waters because of the reduction of light penetration by turbidity. Calculations based on the oxygen production profiles suggest that the depth of the zone which is sufficiently illuminated for net photosynthesis to occur was not sufficient in the estuary as a whole to allow the daily photosynthetic production of oxygen to balance respiration of the phytoplankton. This conclusion agreed with the observation that there was no great difference in the DO concentrations between day and night and also confirmed that the effect of algae on oxygen balance was more a question of death and decay than of photosynthesis. It was concluded that denitrification, meaning specifically the reduction of nitrate to nitrogen, occurs in the estuary. Laboratory experiments indicated that denitrification could almost certainly occur in the Thames Estuary in the presence of DO, in concentrations up to about 5 per cent of the air saturation value.

Although no experimental work supports the view, it was suggested that the sulfide in the estuary was formed mainly by sulfate-reducing bacteria rather than by the breakdown of sulfur-containing organic compounds by sulfydryl-splitting bacteria. The loss of reduced sulfate, although known only approximately, was clearly a fairly small factor in the oxygen balance of the estuary, but the effect of reduction of nitrate was found to have far greater implications than was previously realized.

An ecological survey of the Houston Ship Channel and adjacent bays was initiated in the summer of 1957 with data collected at frequent regular intervals (33). In the ship channel a DO gradient existed from a low concentration in the upper channel to near normal concentration at the lower boundary of the survey area. The DO in the ship channel below the mouth of the San Jacinto River was influenced greatly by the flow rate of the river, which is in turn largely influenced by rainfall. Studies of bottom samples demonstrated that extensive silting has occurred in the ship channel and bays. Low DO, hydrogen sulfide production, and the high organic content of the mud in the channel, all indicative of organic pollution, prevent the establishment of a normal bottom fauna. In the bays adjacent to the channel, the DO concentration is independent of the flow rate of the San Jacinto River, being dependent on oxygen production by phytoplankton, and at certain seasons of the year fluctuating widely in a diurnal cycle. The concentration

may range from supersaturation to extremely low concentrations in a relatively short period. A small temperature gradient was found in the ship channel, the temperature being two or three degrees higher in the upper channel than in the lower survey area. When the DO level is sufficient, a large and diverse population exists throughout the bays in the survey area and for some distance beyond. The species composition of this population varies with the season, with predominantly marine fishes during the summer when the salinity is high, and predominantly fresh water fishes when the salinity is lowered. Both the number of species and diversity of fishes present decreased up the channel.

A survey of the Little Patuxent River, Maryland, was made to determine present water quality and fish population in a 12.8-mile portion of the river (187). Findings indicated that existing discharges do not exert a deleterious effect on the river. The DO level was entirely satisfactory to support a good mixed fish fauna. Minimum DO was 6.3 mg/l. All other characteristics tested revealed water quality well suited to aquatic life.

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Environmental Requirements for Aquatic Life

Settleable Solids

Very often silt pollution is overlooked during routine pollutional surveys. The detrimental effect of silt pollution on streams was demonstrated in a study carried out on the Truckee River and Cold Creek in California (45). The siltation resulted from highway construction and associated activity but was primarily the result of unsettled gravel washings entering Cold Creek over a three-month period. Cold Creek samples from the polluted zone indicated a significant reduction in bottom organisms and showed that trout were in significantly poorer condition. In the Truckee River bottom organisms and algae were significantly fewer in number and weight in those samples taken from the silted zone.

As a result of a study carried out in Buzzards Bay, Massachusetts (191), it was concluded that the similarity in the silt-clay content of bottom area was important in determining the degree of faunal uniformity between paired samples. Sandy locations were characterized by nematodes restricted to this habitat, particularly *Odonotphora* and *Leptonemella*. A silty habitat showed an abundance of several nematodes, particularly *Terschellingia* and *Kinorhynchs*.

Dissolved Solids

"Red Tides" in the Gulf of Mexico caused by the dinoflagellate, *Gymnodinium breve*, have been established as being closely associated with mass mortalities among marine life. The sporadic nature of these outbreaks led observers in research on a connection between environmental factors, chiefly salinity, and the blooms (5). Through the use of a completely synthetic medium with differing major salt content, growth in the various salt concentrations was measured by visual examination. It was found that *Gymnodinium breve* grew well throughout a salinity range of 27 to 37 ppt. Salt concentrations of 13.7 ppt contained no visible live dinoflagellates. The results suggest that the salinity range tolerance is less for *Gymnodinium breve* than other dinoflagellates. Reduced salinity itself was not a biologically essential factor for good growth in cul-

ture. The presence of dissolved nutrients from land drainage was also a deciding factor in the field. High salinity may limit the growth of this organism only in areas in which high evaporation with low runoff and mixing cause salt concentrations to rise well above offshore values. However, low salinity may be a limiting factor in estuarine environments. The relatively close salinity tolerance of *Gymnodinium breve* may explain the localized distribution of dense populations of this dinoflagellate.

In other work (97) experiments were carried out with a large number of marine zooplanktonic organisms which are also generally considered to be stenohaline, in order to test their tolerance to increased and decreased salinity. Survival times were shorter for increased salinities than those for corresponding decreased salinities.

However, the data suggest that salinity is not the limiting factor for the distribution of these forms, since the majority of them can withstand salinity changes much greater than those found in the open sea.

In testing the effects of salinity of natural waters on various species of trout (133), it was found the magnesium carbonate was more toxic than calcium sulfate, calcium carbonate, and magnesium sulfate. Magnesium sulfate was the least toxic of the four salts tested. The carbonate ion was found to be the most toxic of the ions tested. The salinity experiments indicated that the toxicity of magnesium carbonate and calcium carbonate is reduced by the presence of sulfate ion as either the calcium or magnesium salt.

Temperature

When fish and many other poikilotherms, adapted normally to moderate and high temperatures, are artificially acclimated to a given low temperature, their metabolism tends to drop to a level below that of species naturally adapted to a given low temperature (195). The comparatively high metabolism of the naturally occurring cold adapted forms is known as "cold adaptation."

Metabolic characteristics were determined for *Trematomus bernacchii*, which is an antarctic benthic species living at year-round temperatures of -1.8 to -1.9°C. Metabolism was measured on the basis of oxygen uptake of fish confined to a closed chamber. Oxygen uptake rates increased with temperature from -1.9°C to about 0°; the rates tended to decrease with temperature increases above 0°. Thus, the species is quite stenothermal.

Oxygen

The significance of proper oxygenation of water during the developmental stages of fish eggs and embryos has been clearly demonstrated. Eggs of rainbow trout were hatched under two different oxygen conditions, in water with a normal oxygen content and that with a 50-per cent oxygen deficit (83). In incubating eggs in water with a content of 4.7 to 5.8 mg/l, oxygen losses to the moment of hatching reached 13 per cent as against 5.7 per cent for the control group. Mortality of alevins in the post embryo stage reached 94 per cent in conditions of constant oxygen deficit. Death of alevins infested with blue-sac disease was violent. Most of the alevins died within a week after hatching. Embryonic development under oxygen deficit was retarded 386 days as compared to control eggs (298 days). In addition, resorption of the yolk-sac was retarded by more than 10 days as compared to control alevins.

In other work (75), lake trout embryos were exposed to DO levels approximating 2.5, 3.5, 4.5, and 10.5 mg/l at each of four temperatures, 2.5, 5.0, 7.5, and 10°C. The three lower oxygen levels caused retardations in the developmental rates resulting in delayed hatching and lengthening of the hatching period, reduction of vitelline circulatory structures and abnormalities

of head and trunk. The low oxygen levels at 10°C caused total mortality just prior to hatching.

Toxic Materials and Wastes

Bio-Assay Methods

Numerous methods have been devised to test the toxicity of pollutants and other materials to aquatic life. Many of these tests employ different organisms while others utilize new methods and equipment. As a test for the biological qualities of sea water, the rapidity of the development of the larvae of the sea urchin was used (25). In other work (153), the effects of varying concentrations of DO were studied by determining the survival on the polychaete, *Capitella capitata*. Another interesting approach to a bio-assay method was to study the effects of industrial wastes upon *Asari*, an important bivalve (67). In normal sea water the bivalve would have its shell open. If toxic substances were introduced they shut the shell. The amount of shell opening or closing was observed for the quantal response instead of mortality.

A new electrical-biological method was devised to test the effects of wastewaters to fishes (87). The method is based on the registering of the nervous-physiological changes in fish caused by the various dilutions of the wastewater. Another test was employed in which the effects of industrial wastes on phosphorus assimilation by lavers, one of the more important marine algae, was studied (68). Paper electrophoresis of the blood sera from fishes exposed to industrial wastes and chemicals has also been employed as a bio-assay method (69).

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Metals

In Japan, as elsewhere, there is an abundance of pollution problems resulting from copper-containing wastes. As a result, various research projects have sought to determine the effect of copper on aquatic life. The effects of copper on oysters were studied in vitro (70). The 96-hr TL_m value of copper to oysters was estimated at 1.9 mg/l. A dissociation and regressive change of the digestive diverticula and desquamation and necrosis of the stomach epithelia were observed histopathologically. On the other hand, a decrease in ribonucleic acid was observed cytochemically. It was also estimated that oysters cultured in sea water mixed with small quantities of copper deposited the metal in their bodies and thus become unfit as a food substance.

In another study the effects of copper mine wastes on insects and their larvae were examined (82). Insect samples were collected quantitatively from 10 stations on a river which received effluent from the Ashio Copper Mine, near Nikko in Tochigi Prefecture. Examination of the insects revealed that the effect of the river pollution was distinct. Near the copper mine effluent there was a decided decrease in both the number of species and of individuals. At a distance of 27 to 38 km from the mine effluent, there was an apparent recovery of the aquatic fauna.

The toxicity of zinc sulfate to rainbow trout in waters of different chemical and physical properties was investigated (127). The results showed that zinc sulfate is less toxic in hard water than in soft water. Solutions of zinc sulfate containing calcium chloride were less toxic than those containing an equivalent concentration of calcium as bicarbonate. An increase in temperature decreased survival of rainbow

trout in zinc sulfate in hard water, but the threshold concentration was not appreciably affected by changes in temperature. Reduction in DO increased the toxicity of zinc sulfate but the effect was reduced when the fish were previously acclimated to lower oxygen concentrations of test water. The cause of death of fish in solutions of zinc sulfate was not by precipitation of mucus on the gills but probably by damage to the gill epithelium.

An interesting study was conducted to determine the animalizing effects of zinc ions on the development of the eggs of the sea urchin, *Paracentrotus lividus* (124). The susceptibility of the embryos to zinc ions was found to be stronger at the beginning of development. Treatment by zinc ions had to be extended beyond the blastula stage in order to get the animalizing effects maximally expressed. The evolution of susceptibility to zinc ions during development was similar to the evolution of susceptibility to lithium ions. The action of a vegetalizing agent, such as lithium chloride, on the animalizing effects of zinc ions was studied in cultures with zinc chloride at a concentration of 5×10^{-4} M and lithium chloride at concentrations varying over a fairly wide range. It was found that with a decrease in concentration of lithium chloride the embryos pass from vegetalized to animalized types. Very small plutei were obtained with suitable concentrations of lithium chloride. Both zinc ions at concentrations of 5×10^{-6} and 10^{-5} M and the acid polysulfonic dye, Evans Blue, at a concentration of 5×10^{-6} M, induced the development of the radial larvae. Acting together at these concentrations, these agents exerted an animalizing effect. Thus the summation of the effects of these two animalizing agents was demonstrated.

Pesticides

A field experiment was conducted to determine the effect of an emulsified mixture of benzene hexachloride used for spraying sawlogs on coho salmon fry, *Oncorhynchus kisutch* (101). The results demonstrated that application of the emulsified benzene hexachloride at the rate of 12.3 lb per 34,848 sq ft were lethal to the fry when held within 1 ft of the surface. The results obtained from holding the fish in a vertical gradient showed that fish held at depths greater than 1 ft were not killed.

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Toxic Materials Produced by Algae

An attempt was made to establish a relationship between chemical components and bacterial numbers in water to phytoplankton and zooplankton populations (61). It was theorized that masses of algae excrete substances which limit the number of bacteria present in waters. Also, the percentage of dissolved organic material in the water does not alone determine the massive presence of Cyanophyceae (blue-green algae), but it is the nature of the substances which is the determining factor. The biogenic value of waters of the same pond varies for the same species of algae in the course of a year. These variations do not seem to be directly linked with temperature,

light, or pH, but to the presence of thermostable or thermolabile organic substances.

Other Toxic Materials

Experimental work was conducted to determine the influence of carbon dioxide on the toxicity of un-ionized ammonia molecule. It is the concentration of the un-ionized ammonia at the gill surface which determines the toxicity. The variation in toxicity can be attributed to the increase in the concentration of carbon dioxide in the respiratory coater as it passes over the gill surface. Thus, carbon dioxide decreases the pH and the concentration of un-ionized ammonia present. The effect of these factors on the carbon dioxide from the gill surface depends on the initial concentration of free carbon dioxide in the bulk of the solution.

Non-ionic, anionic, and cationic synthetic surface active compounds were tested for their effect on the growth of green algae (199). In concentrations of 1.0, 5.0, and 10.0 mg/l of a non-ionic compound, algal growth was stimulated during the first few days but there was a later retardation. A concentration of 50 mg/l retarded growth from the beginning. Concentrations of a cationic compound greater than 5 mg/l definitely hindered growth. At a concentration of 0.5 mg/l there was a toxic effect for two weeks and then rapid growth took place. At a concentration of 1.0 mg/l somewhat the same effect occurred. Anionic compounds in concentrations of 1.0 mg/l had no effect while concentrations of 5.0 and 10.0 mg/l were slightly toxic. However, after 25 days the toxic effect disappeared and growth took place.

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Effect of Organic Enrichment

The fish populations of two major arms of a reservoir receiving sewage and industrial wastes having combined population equivalents of 20,910 and 24,560, respectively, were compared with a non-polluted arm (177). If catch per unit effort were considered as a measure of population size, the total fish population in the two polluted arms of the reservoir was significantly higher than the non-polluted arm. The population of both coarse and game species was higher in the polluted arms. However, the percentage composition of game species was higher in the non-polluted area. Reproduction and survival of large-mouth bass through the late summer was definitely greater in the non-polluted arm.

Westlake (188) points out that pollution causes faunal changes and these in turn cause many of the chemical and

physical changes in the water due to their metabolism. For instance, laboratory experiments have shown that heavy concentrations of *Asellus* and *Chironomus* larvae in polluted areas are capable of decreasing the DO while dense plant populations have been reported to cause great diurnal and seasonal changes in rivers such as from 20 to 230 per cent change in the average DO within 12 hr. It is pointed out that to calculate and predict the effects of organic pollution, the biological causes of changes in DO and of associated changes in pH and substances such as carbon dioxide, ammonia, nitrates, and sulfides must be studied.

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Radioactive Wastes

Using the ashed weight basis for comparing gross beta radioactivity, it was shown by Bonham (24) that the 1956 series of nuclear tests contributed not more than one per cent as much radioactivity to plankton as the original 1954 fallout. The 1958 series contributed not more than five per cent as much as the 1956 series. In bottom samples, there was no appreciable reduction of activity and there was no correlation between the radioactivity of plankton and bottom samples at the same locality. Also, the levels of activity were equally high in plankton taken in coarse and fine nets. It was also shown that results were nearly twice as consistent when based on ash as on wet weights.

Donaldson and Foster (55) have pointed out some of the effects of radiation on aquatic organisms. The lower more primitive forms of aquatic organisms are generally more resistant to radiation than are vertebrate forms. The algae and protozoa are the most resistant with LD_{50} values in the order of many thousands of roentgens. Fish are the most sensitive with an LD_{50} of about 1,000 r. In two species of snails it has been observed that a species difference may determine the amount of time which elapses after radiation and before death.

Radiosensitivity has been correlated with the metabolic rate of the dividing cell. For example, dry, dormant *Artemia* eggs are quite resistant. Also, radiosensitivity tends to decrease with age. The LD_{50} values range from 50 to 100 r for gametes within the parent fish to about 1,500 r for an adult trout.

Retardation in rate of growth of snails exposed to radiation has been reported. The rate of growth of young fish during their first year was found to be directly affected by the amount of irradiation received by the parent fish.

The tissues most sensitive to radioactivity are those in rapid division and growth. The gonads are the most sensitive tissue and next the hemopoietic tissue. Radiation of the eggs of the chinook salmon causes a reduction in the number of primordial germ cells in the gonads, as well as in the number of glomerulii in the kidneys. Typical syndromes of radiation of 1,500 to 2,500 r on trout were mass hemorrhage, petechiae, and ecchymosis. Eggs ex-

posed to radiation produce malformations.

Exposure to radiation may cause damage to the chromosomes or genes. X-radiation of the eggs and sperms of the sea urchin *Arbacia* cause delay of the first cleavage. Spermatozoa are three to four times as sensitive to radiation as ova. Irradiation of parent fish increased the frequency of occurrence of malformations of embryos compared with non-irradiated fish.

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Microbiology

During the first week of January 1960 the Ravena-Coeyman's area, New York (64), experienced a sudden extensive outbreak of dysentery due to *Shigella sonnei*. About 1,400 cases occurred in a population of 3,200. The only common source was municipal water from Hannacroix Creek. Approximately one-third of the population of Roosevelt, Utah, became ill during an epidemic of dysentery due to *S. flexneri* 6 (57). Epidemiological studies pointed to an old irrigation canal as the contaminated water source. Another small outbreak of 12 cases due to *S. flexneri 2a* was reported from a small provincial hospital in France (141). The drinking water was contaminated by a closelying defective sewer. One hundred sixty-nine cases of infectious hepatitis occurred in Curwensville, Pennsylvania, and environs in March and April 1956 (136). The probable vehicle of transmission was the municipal water supply. An outbreak of enteritis in a children's camp in Hungary was associated with *Escherichia coli* serotype 124:72:32 (125). No new cases appeared after use of the spring water containing this organism was stopped. A morbidity survey (149) of six Rocky Mountain communities revealed a significant relationship between the sanitary quality of a community's water supply and the incidence of gastrointestinal illness occurring. It was also noted that the attack rate among people who had been exposed less than two years to the contaminated water was twice that of people exposed more than two years. During the height of an epizootic in Oregon meadow mice (microtus montanus) (106), *Pasteurella tularensis* was found in the waters of streams and shallow wells. *P. tularensis* was also isolated from 3 of 22 water samples from Castor Swamp in Canada during an epizootic of tularemia in muskrats (54). Water-borne outbreaks of tularemia in Russia (179) were attributed to well waters contaminated by dead rodents and to water from running streams. Dauer and Davids (48) in their summary of water-borne disease in 1959 (U. S.) reported seven outbreaks. There were three of typhoid fever, one each of amoebiasis, hepatitis, chemical poisoning, and one combined *E. coli* and enterococci.

In a study of sewage contamination of coastal waters in England and Wales (42), the Committee on Bathing Beach Contamination of the Public Health Laboratory Service concluded that bathing in sewage-polluted sea water carries only a negligible risk to health, even on beaches that are aesthetically very unsatisfactory. Four cases of paratyphoid fever, probably due to bathing were recorded. Isolation of various salmonella serotypes increased from 13.3 per cent in samples with less than 1,000 coliform organisms per 100 ml to 40.0 per cent in samples with over 10,000 coliforms per 100 ml. Poliovirus was not isolated from the small number of sea water samples examined. Khait (113) found that bacteria of the coli and shigella groups survive in sea water for a long time and thought their presence may be of great epidemiologic significance.

Darrasse *et al.* (47) isolated Salmonella of five serotypes from tap

water in Dakar. A reservoir of the supply was contaminated by lizard droppings. Heinrich and Pulverer (90) described a method for quantitatively estimating Salmonella organisms in river water, sewage, and mud. Dyadichev (59) concluded that the most important factor inhibiting the growth of intestinal pathogenic bacteria in water was the lack of sufficient nutritive materials. *Vibrio cholerae* were recovered from twelve of eighty-nine water samples of the Hooghly River at Calcutta (1). The positive isolations were spread evenly over the entire eight-month study which covered both epidemic and non-epidemic periods, including the monsoon. The causitive organisms of erysipeloid (*Ery. rhusiopathiae*) and listeriosis (*L. monocytogenes*) have been isolated from the waters of several small streams in Russia (144). Coudert and Saez (46) examined 22 samples from the water supply of Lyon, France, for the presence of fungi capable of causing disease in man. *Aspergillus fumigatus* and *Geotrichum candidum*, along with other fungi, were found in the survey. Cooke and Bartsch (44) reported that 26 named species of aquatic Phycomycetes were found in streams of southwestern Ohio and the Potomac River. Sixteen of 22 water supplies contained nematodes in both raw and finished water (36). Of the 16 supplies showing nematodes, 14 used river water as their raw source. These results were obtained using the method described by Chang (37). After studying the distribution of free-living nematodes in the river Blyth estuary, Northumberland, Capstick (31) concluded that the nematode population of the estuary was primarily marine in origin.

Heukelekian (93) (94) reviewed the methods of determining bacterial populations, their significance, and the types of bacteria found in polluted fresh water. In discussing indicators of pollution in drinking water, Kabler and Clark (104) stated that insofar as bacterial pathogens are concerned, the coliform group is considered a reliable indicator of the adequacy of treatment. As an indicator of pollution in drinking water systems, and indirectly, as an indicator of the protection provided, the coliform group is preferred to fecal coliforms (*E. coli*). According to Taylor (175) the most important function of the analytical control of water supplies is to ensure freedom from the causitive organisms of enteric diseases, and their absence from purified water may be presumed with confidence by demonstrating by laboratory test the absence of normal intestinal flora, in particular *E. coli*. In polluted river waters, Keller (108) considered the sanitary quality to be dependent not on the total number of coliform organisms present, but on the number of *E. coli* present as determined by the use of MacConkey broth at 44.5°C for 48 hr. Enterococci (109) survived longer than *E. coli* and can be regarded as indicators of "delayed" pollution when *E. coli* are absent or present in small numbers. Mikhaliuk (132) stated that the coli index and bacterial counts remain the most practical methods for determining water contamination, but full assay of fungal microflora is recommended where more precise characteristics of water reservoirs are required. In Ceylon (107) *E. coli* accounted for only 50 per cent of the positive samples on MacConkey broth at 44°C, and 55.5 per cent on brilliant green bile broth. It appeared, therefore, that under conditions in Ceylon a combined test using fermentation of lactose and indole production at 44°C did not differentiate *E. coli I* completely from other coliform organisms. Petersen and Boring (150) showed that drainage from flood irrigation and the presence of cattle in semi-isolated mountain streams affected the otherwise uniform densities of coliform serotypes. In North Wales (41) water samples stored 24 hr before examination frequently showed changes

in both total coliform and *E. coli* counts, reductions in bacterial numbers being much more frequent than increases. There tended to be greater losses in coliform organisms than of *E. coli*.

Spaander and Roest (166) have recommended a modified citrate medium for the detection of fecal streptococci in drinking water. Barnes (19) found that the addition of tetrazolium to acetate agar at pH 6.0 made it possible to distinguish colonies of *St. faecalis* and variants *zymogenes* and *liquefaciens* from *St. faecium* and *St. durans*. Kenner *et al.* (111) suggested that a careful classification of the streptococcal groups permitted a qualitative interpretation of the possible sources of human versus animal pollution, and further suggested that the fecal streptococcus group should include the enterococcus group, *St. mitissalivarius*, *St. bovis* group, *St. equinus* and certain atypical types. Bartley and Slanetz (21) pointed out that the nomenclature and classification of fecal streptococci represented many problems. Rather than limit this term to those streptococci that meet the Sherman criteria, it is desirable to have it include all streptococci commonly inhabiting the intestinal tract of man and animals. Using a sodium azide-crystal violet medium, Kjellander (120) found streptococci to be a more sensitive indicator of pollution in water. The presence of sorbitol fermenting streptococci indicated human pollution. Ramadan (152) suggested that the streptococcal index may serve as a better safeguard than the coliform tests, both in judgment of chlorination efficiency and also in the control of pathogens known to resist chlorination and similar treatments.

Gyllenberg and Niemela (84) described a selective medium for demonstrating *Lactobacillus bifidus* which is normally found in the feces of human adults. These organisms are quite numerous in feces (85) and exhibit some similarities in survival to coliforms and enterococci. The authors concluded that more data on the distribution and persistence of bifid bacteria in nature are desirable.

Following an evaluation of membrane filter techniques for appraising Ohio River water quality, Streeter and Robertson (172) recommended the technique as an acceptable optional procedure to the most probable number (MPN) method. Burman (29) discussed several differences in the use of British, German, and American membranes, and detailed a practical substitute for the resuscitation MF test. Results agreed well with multiple tube tests with savings in materials and labor. Just and Zieminska (103) compared the single-stage membrane filter and bacto-strip methods with the fermentation tube method of determining coliform bacteria in water. Results of the bacto-strip method were inconsistent, and usually about 50 per cent less than the MPN. The membrane filter gave results comparable with the multiple tube method.

McCarthy (129) reported that a given amount of chlorine, properly mixed with sulfamic acid will give greater kills of bacteria than the same amount of chlorine alone or as chloramine. Loss of active chlorine due to sunlight, wind and splashing, and casual organic matter was definitely reduced. Kelly and Sanderson (110) found that polioviruses and Coxsackie viruses in water were inactivated by combined residual chlorine. At 25°C and a pH of 7, a concentration of at least 9 mg/l was necessary for inactivation of poliovirus in a contact period of 30 min; 0.5 mg/l required a contact period of more than 7 hr. The rate of bacterial destruction by monobromamine (102) was proportional to the concentration of the monobromamine ion, which was affected by the pH. The monobromamine base had bactericidal powers similar to that of monochloramine. Goldstein *et al.* (80)

developed a pasteurizing unit which has performed satisfactorily in destroying coliform organisms. The total cost of water pasteurization on a household scale was estimated to be approximately $1.00 per 1,000 gal.

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Slime Growths

Scheuring (158) described the various ways in which *Sphaerotilus natans* develops in still and flowing water and the effects of temperature, pH value, and rate of flow on the organism. Two forms of apparatus were used in experiments with the bacterium. In one the culture liquid remained the same but was kept in continuous circulation and aerated by a paddle wheel; in the other a continuous flow of culture liquid was passed through a filter candle. By these means experiments on oxygen requirements and oxygen demand, tolerance of salt, sources of available nitrogen and carbon, dilution of substrate, and intermittent discharge of substrate were performed. Brief reference was made to unexplained problems of alterations in the quantity and type of growth in the same wastewater.

For investigations of pollution on the lower Columbia and Willamette Rivers three pieces of field equipment were developed or adapted from existing models by Wilson *et al.* (194) for the determination of slimes in rivers. They were the bottom trawl to locate the areas of active *Sphaerotilus* growth; the tile box sampler to correlate areas of growth and growth characteristics of various concentrations of nutrients and certain physical factors; and the Reighard tow net to determine the quality, quantity, and distribution of detached and suspended slimes. The designs and operations of the three types of apparatus were described and illustrated.

Adam (2) observed heavy growth of *Sphaerotilus natans* from September until spring in streams into which wastewaters from fruit juice works and distilleries were emptied. The growths caused a high oxygen demand. Floculation of the wastewaters failed and biological treatment was only possible if the wastewaters were diluted with more than 95 per cent dilution water or sewage.

Rheinheimer (155) found in a series of experiments that strong pollution with organic compounds could lead to mass development of *Sphaerotilus natans*. The mass development caused a phosphate shortage and delayed nitrification. However, the quality of the Elbe water at the time of these experiments made the risk of mass development of *Sphaerotilus* slight.

Heukelekian (93) (94) described the growth of *Sphaerotilus* in streams, methods for detecting and studying the organism, and its importance in the

stabilization of organic matter in polluted waters in shallow streams.

Tkachenko and Drublyanets (178) observed the growth of *Sphaerotilus dichotomus* during the purification of wastewater from a hydrolysis factory in aerotanks. This growth led to the formation of a "swollen" silt and lowered the degree of purification of the aerotank. Active growth of the filamentous bacterium was promoted by the high concentration of organic matter, chiefly carbohydrates, and the acid reaction of the wastewater. The most useful measure used to restrict the "swelling" of the activated silt was dilution of the wastewater which reduced the carbohydrate content and the acidity.

Dondero and Okrend (56) reported a natural association of *Sphaerotilus* and a pigmented rod-shaped bacterium which produced a pink slime infestation in some polluted streams. Experiments proved that pigmentation was not induced in *Sphaerotilus* by diffusion of metabolites or pigment from the rod-shaped organism. The association appeared to result from the adhesion of the pigmented rods to each other and to the filaments of *Sphaerotilus*.

Brighton (26) observed the contamination of a chalk borehole with *Leptothrix* and *Beggiatoa*. They formed a thick mat on the pumps and greatly reduced the maximum production of the borehole. The chlorinated water had a medicinal odor and an astringent taste. Pollution of the aquifer by silo drainage from pea vines may have been responsible for the difficulty. The slime was removed by treatment of the borehole with sodium hypochlorite and subsequent treatment with strong HCl. The organisms were found to be killed by free chlorine residuals of 1.0 to 1.25 mg/l in 30 min.

Wolfe (196) studied samples of *Crenothrix polyspora* obtained from the filters of the water plant at Malmo, Sweden, and those associated with a brown hair-like bacterium from the filter galleries at the Richmond Water Works Corporation, Richmond, Indiana. On the basis of the samples he studied and descriptions of photomicrographs given by earlier investigators, he believes that *Crenothrix* may not actively deposit iron or manganese in its filaments. As the organism has never been obtained in pure culture, its mode of nutrition is unknown. Wolfe (197) tentatively identified the brown hair-like bacterium as *Clonothrix putealis* (*Clonothrix fusca*). The organism concentrates iron and manganese in its sheaths and fluorishes in a water supply containing, by chemical analysis, no detectable manganese and less than 0.02 mg/l iron. Iron and manganese account for 28 per cent of the total dry weight of the organism, the ratio of iron to manganese being 0.9. Attempts to culture the bacterium were unsuccessful.

The iron bacteria that occur in Lake Glubokoe in the Moscow region of Russia were studied by Sokolova (163). Maximum growth of the organisms occur when the water mass is enriched with soluble iron compounds carried up from the bottom; at these periods, the time of the spring and autumn flow, the iron bacteria comprise 7 to 12 per cent of the microorganisms in the lake. A definite relationship was found in the vertical distribution of certain species and an increase was noted in iron concentration and total number of iron bacteria toward the bottom. The problems of classification of these organisms were discussed.

Both Kalinenko (105) and Ulanovsky *et al.* (181) found *Leptothrix* as one of the organisms developing on metal plates suspended in sea water. They believe the organisms are implacated in the initiation of galvanic pairs and accelerate the electrochemical processes of metal corrosion.

Rheinheimer (156), while studying the yearly rhythm of the bacterial numbers in the Elbe between Schnackenburg and Hamburg, noted briefly that

Thiothrix and *Cladothrix* increased during the winter months, which was the period of maximum bacterial count.

Vouk (184) described a variant form of the iron bacterium, *Gallionella*, which was found at the outlet of the warm springs in Bad Gastein. He reported that it was characterized by the zig-zag spiral windings of the secretion strands and many bacterial cells positioned laterally on the strands. It is described as a new species and given the name *Gallionella schcminzkyi*.

Delaporte and Vlassoff (49) reported the industrial importance of bacterial capsular material, and its significance in "slimes" is discussed. Some of the factors affecting the metabolic processes of microorganisms, including a large section on the sheathed, filamentous iron bacteria, was reviewed. The value of research into the use of enzyme inhibitors as a means of checking bacterial capsule production was suggested as part of a program aimed at freeing industry of troublesome slimes.

Chemistry

Nitrogen transformations have been undergoing close scrutiny. Symons *et al.* (173) studied the pathway of degradation of nitrogenous material in sewage disposal. Dugdale *et al.* (58) reported nitrogen fixation in U. S. lake water sometimes at high rates. N^{15} was used as a tracer. Per (148) studied nitrogen fixation in Latvian lakes in relation to water composition and bacteria population. The South African Council for Scientific and Industrial Research (164) reports investigations of various aspects of nitrogen metabolism. Of particular interest are laboratory studies of the denitrification of nitrates.

Wheatland (189) studied a complex and varied series of carbon, nitrogen, and sulfur cycles in the Thames Estuary. Gameson (73) reported on the oxygen balance in the Thames Estuary, considering a diversity of factors such as photosynthesis, nitrate, and sulfate reduction as well as atmospheric oxygen.

A number of studies of chemical composition are of interest. Hendrickson and Krieger (91) reported on correlations between discharge and seasonal factors with mineral chemical composition of Kentucky surface waters. Gammerton (74) followed the evolution of water composition in a new impoundment with a large organic load on the bottom. Stratification was important. Palange (146) summarized data on the lower Mississippi from reports of the National Water Quality Network. Painter and Viney (145) reported on sewage composition. Bunch *et al.* (28) examined a number of secondary effluents and reported difficulty in characterizing the principal materials present. Rosen *et al.* (157) attempted to chemically differentiate offshore oil seeps from other possible oily pollutants of beaches, while Foxworthy and Stone (63) attacked the problems of beach deposits of off-shore oil seeps.

Harkness and Jenkins (88) studied the composition and stability of detergent foams. Of interest is their observation that sewage foams are high in nitrogenous material and that this may be an important factor in foam stability.

Oxygen Sag and Stream Self-Purification

The findings of a large-scale study of deoxygenation rate constants were reported by Schroepfer *et al.* (159). This work was performed over the last five years and involved more than 5,000 BOD determinations of raw and treated municipal wastes and Mississippi River waters. It was found that the commonly used monomolecular law did not describe the course of deoxygenation of raw sewage and certain treated effluents during the first day, although biologically treated effluents were adequately described. The course of deoxygenation of river water sam-

ples also followed the familiar monomolecular decay pattern. Raw sewage, primary effluent, and chemical treatment effluent were found to be characterized by a rapidly decreasing K value during the first day of incubation. An empirical expression describing the course of this type of deoxygenation was developed and had the form:

$$BOD_t = a \frac{BOD_5}{5} t^{(1+b)}$$

where the BOD at time t is related to the 5-day BOD by means of a slope b and an intercept a (at $t = 1$) from a graph of the expression: log $[(BOD_t/t)/(BOD_5/5)]$ versus time. It was noted by the authors that two simultaneous first-order reactions with different K values would also adequately express such data.

Sheehy (161) presented two rapid methods for computation of the reaction rate constant K using BOD observations at whole or fractional day intervals. A circular slide rule and graphical methods were employed. Extensive measurements of the BOD velocity constant K of Boston-South Metropolitan sewage were carried out by Fisichelli and Palombo (62). The mean K value of 0.14 was found for entering raw sewage, the value of 0.15 for primary effluent. Slightly higher values were found by exeluding flows containing large amounts of storm water.

Reaeration of oxygen-deficient natural waters by passage through turbines of hydroelectric power installations was evaluated by Wiley *et al.* (192). Tests at six installations showed that by introducing air into the turbines, waters at 40-per cent oxygen saturation or less could be practicably reaerated by this means. Absorption rates ranged from 1,600 to 8,200 lb oxygen per day per 1,000 cfs of flow. Power losses of 2.5 to 10.6 per cent were experienced, with 1.8 to 5.6 lb of oxygen being absorbed for each kilowatt-hour of power lost. By this means the authors estimated a cost of $3.00 to $15.00 per ton of oxygen absorbed.

Artificial reaeration of lakes (9) and impounding reservoirs (27) continues to receive attention. Methods used or proposed include compressed air injection, paddles, Kessener brushes, sprays, and oxygenating chemicals.

A laboratory investigation (180) of the solubility of oxygen in water has for practical purposes confirmed the oxygen saturation values as reported in "Standard Methods" (168) although slightly different values (lower by 0.05 to 0.20 mg/l) were found at temperatures above 10°C.

A formulation for the oxygen sag curve in tidal estuaries has been developed by O'Connor (143). The differential equation for steady state conditions which is presented describes the interrelationship of the various factors which affect the oxygen balance within an estuary; viz., seaward displacement of pollutant by river inflow, pollutant dispersion by turbulent mixing, pollutant decay rate, and the rate of atmospheric reaeration. Methods for calculating the coefficients necessary for a solution are given. A turbulent transport coefficient e is calculated from observed salinity distribution; the net seaward flow U is computed from river inflow; and the reaeration rate constant K_2 is obtained by the use of mean tidal velocities and depths averaged over the section and the tidal cycle. In these computations of the reaeration rate constant, no provision for photosynthetic oxygen production is included. These coefficients are assumed to remain constant over the estuary length being studied. The remaining coefficient K_1 the deoxygenation rate constant, is derived as a function of two of the previously determined coefficients, namely, U and e, together with observed five-day BOD concentrations in the estuary. Application of the equation to a vertically unstratified, laterally homogenous estuary with as-

sumed steady river inflow is demonstrated.

Glenn and Cowherd (77) have used a sine function to describe the observed relationship between dissolved oxygen values and time referred to the tidal cycle in the New York harbor area. The authors suggest that the derived relationship may be used to determine conditions throughout the estuary at any stage of the tidal cycle from a minimal number of observations.

The evaluation and characteristics of several European rivers, the Rhone, Tiber, and Maritsa, were carried out in the reports of Chambon (34), Talenti and Lionetti (174), and Adzharov *et al.* (4).

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Stream Studies and Surveys

A growing interest in pollution of the marine environment has been indicated this year. The impetus given to this area of environmental health is indicated by publications of the Committee on Oceanography, National Academy of Sciences, National Research Council (43). In this series of publications in support of a national effort over a 10-yr period recommendations are made to solve problems dealing with ocean resources. Various individual research projects involve a number of governmental agencies and educational institutions. A further milestone which will advance pollution studies in marine waters is a reference text and working handbook on apparatus and methods of oceanography by Barnes (20). The significant use of tracers and models in studies of the dispersion of pollution is pointed to by Huiswaard and Bell (98) who used tritium in their investigation. Carpenter (32) published on the sensitive new tracer Rhodamine-B, developed by the Chesapeake Bay Institute, which was used in a study of the exchange or flushing rate of Baltimore Harbor. It was found that this dye was excellent; it is non-toxic to human and aquatic life, quite soluble in water (two per cent by weight), highly soluble in methanol, and readily detected by its fluorescence. Kent (112) considered turbulent diffusion in a well-mixed turbulent estuary and developed a theory from which quantitative predictions of mean pollutant concentrations can be obtained. Pearson and Holt (147) in writing of water quality and upwelling at Grays Harbor entrance in Washington State discuss that, in studies of pollution of estuaries, the upwelling phenomena may render invalid calculations based on oxygen balance unless actual concentration of dissolved oxygen at the ocean source is determined. Southgate (165) presents significant historical information in summary of the investigations of England's Water Pollution Research Laboratory over the last 10 yr. The studies were directed to ascertaining the causes of the deterioration of sanitary quality of tidal water of the Thames Estuary which has occurred during this century, and to predict what measure would be necessary to eliminate offensive conditions. Koch (123) summarizes reports dealing with investigations involving waste discharges into the sea along European coasts. Stehr (170) discusses sources of pollution in Hamburg Harbor, Germany, dealing with the effects of oil pollution, harbor

refuse, and sources of radioactive pollution.

Fresh water stream, lake, and reservoir studies are receiving an impetus from the development of new techniques, methods, and instrumentation which are being improved each year.

An extremely significant paper by Middleton and Lichtenberg (130) on the measurement of organic contaminants in United States waters deals with the carbon filter technique. Phenyl ether was found, as were general types of chemicals such as nitriles, phenols, synthetic detergents, ketones, etc. Insecticides were detected in several bodies of water, as DDT in the Missouri, Mississippi, and Columbia Rivers, and Aldrin in the Snake River. Concentrations of such insecticides ranged from 1 to 20 mg/1,000 l.

Computational aids for forecasting and measuring water quality are becoming established and show promise of being effective implements for those conducting investigations and field surveys of polluted water. Gloyna and Schechter (78) have published on a method involving harmonic analysis and various computer techniques. An example, showing how a complex water quality problem can be solved, relates to buildup of chlorides in a reservoir following certain conditions of water reuse. An anonymous article (10) discusses an automatic water-quality measuring monitoring system that will go into operation this fall to aid in pollution control of the Ohio River. The robot monitors will relay water quality information from 40 points along the Ohio River to the Cincinnati headquarters of the Ohio River Valley Water Sanitation Commission. The water analyzers located at key points along the river will monitor dissolved oxygen, chloride, hydrogen ion, specific conductance, oxidation-reduction potential, temperature, and solar radiation. This information will be transmitted to a receiver and data transcriber located in Cincinnati. This new robot system will replace ORSANCO's present network of 43 manually operated stations. Each robot monitor comprises three 21- × 21- × 24-in. cubicles stacked in a weatherproof, stainless steel cabinet. Flow cells and detectors are in the bottom cubicle, electronic measuring instruments in the center, and the telemeter transmitter in the top cubicle. The system will cost close to $250,000.

Heat is more and more being added to national waterways through industrial expansion; today, it is a universally recognized pollutant. Temperature relationships in bodies of water have long been effectively related to calculations made in engineering water survey reports. Velz and Gannon (183) have made an important contribution on forecasting heat losses in ponds and streams.

Further consideration is given the use of quantitation of factors related to river pollution by Goda and Nambu (79) obtained from field observations and laboratory experiments. They have dealt with the diffusion and transport of suspended pollutants in rivers and have developed quantitative relations between the discharge of sewage and the dilution factor.

In recent years considerable attention has been given to study of synthetic detergent pollution. Morgan and Engelbrecht (135) present data on phosphate and ABS concentrations in Illinois streams; Hurwitz *et al.* (100) discuss percentages of ABS which may pass through sewage plants and the subsequent hazard as a pollutant to surface water supplies. Spargo (167) writes of studies of the effect of synthetic detergents, primarily of the anionic sulfonate type, on sewage plants and streams of Johannesburg, South Africa. Field investigations indicated that a sewage plant effluent containing 2.5 mg/l of detergent showed no decrease two miles downstream; at 60 miles downstream 60 per cent was still present. Weaver and Coughlin (186)

report on five years of data on the apparent ABS concentration in the Ohio River below Cincinnati. The average value was 0.16 mg/l. It was further observed that during five years of monitoring the concentration was not increasing.

Reports and papers relating to general stream pollution field surveys issued from foreign countries continue to be of interest. An example is the 1959 water pollution report from England (51); of special interest is a section on instruments including: automatic water sampler, recorder for solar radiation, DO recorder with a wide-bore dropping mercury electrode. Also of pertinent interest is a description of methods of radiochemical analyses of water, aquatic vegetation, and mud. International cooperation in developing methods to preserve the water quality of the Rhine River Basin is reported by Schwoerbel *et al.* (160) who considers the over-all river system from its origin in the Alps, through agricultural country, into highly industrialized areas. Pollution of the Rhine at Mannheim is described in detail. A paper from New Zealand by Hogan and Wilkinson (95) deals with pollution of the Avon and Heathcote Rivers from their fresh-water headwaters to their estuary. The effects of season, tide, and river usage as related to pollution are described. The tributaries and fresh-water sections were more polluted during the winter than at other times; however, in the saline tidal section at Heathcote increased biological activity resulted in depletion of dissolved oxygen in summer. Three articles that relate to the chemical and bacteriological pollution of rivers from a general over-all water pollution survey including both municipal and industrial pollution are of interest; one by Chambon (35) deals with the Rivers Rhone and Saone, and two relate to rivers in Poland, the Sola River reported by Musial *et al.* (138) and the Niemen River by Stangenberg (169). An investigation of Lake Zeller in Switzerland by Liepolt (126) is of interest in indicating that it is becoming eutrophic and that steps must be taken to reduce nutrient matter entering it. Details are given relating to the lake's hydrological, morphological, physical, chemical, biological, and bacteriological condition.

Stream Standards

Dieterich (53) reviewed stream purity requirements which are used or proposed in several European countries (Austria, Belgium, England, France, Holland, Luxembourg, and Spain). Based on these requirements and other considerations, he developed a summary classification of water quality desirable for sources of drinking water, recreation, industrial and agricultural uses, and waste disposal. The classification involves 17 indexes of water quality for most of which numerical values are specified.

Germans (76) examined the pros and cons of general standards for waste effluents with relation to various constituents of both domestic sewage and industrial wastes. He concluded general effluent standards are impractical, and that equitable standards for an individual effluent can be established only after careful consideration of both the effluent and the receiving stream. He also suggested that it may become necessary to change any standards that have been established as effluent and stream relationships change.

Mueller (137) discussed requirements for the treatment of sewage in Australia. Although there are no legal standards and specific objectives vary from area to area, the British Sewage Commission recommendations are widely accepted. These recommendations are that both BOD and permanganate consumed values of river water be less than 4 mg/l, albuminoid nitrogen less than 0.45 mg/l, suspended solids less than 15 mg/l, and DO at least 5.7 mg/l. Sewage treatment to

meet the Commission recommendations for less than 20 mg/l of BOD and 30 mg/l of suspended solids in plant effluents usually assures compliance with the recommended stream quality. In New South Wales, Queensland, Tasmania, and West Australia, where intermittent stream flows pose a problem, a BOD of less than 10 mg/l and suspended solids of less than 15 mg/l in sewage effluents are considered desirable. In Victoria, sewage discharged into streams used as sources of water for drinking must contain no coliform bacteria that are detectable in 50 ml of the treated sewage. This necessitates biological treatment followed by chlorination.

Habenicht (86) described considerations controlling the uses of Berlin waters for bathing. Bathing is permitted in waters with a coli titre (minimum quantity of water yielding a positive result) of 0.1, 1.0, or 10.0. Bathers are warned of the risk when the titre is 0.01 and 0.001.

Klimkina (121) recommended maximum permissible concentrations of 0.005 mg/l for both isoprene, to prevent odor, and for dimethyldioxane to prevent toxicity.

Derby *et al.* (52) presented views regarding tentative revisions of the U. S. Public Health Service 1946 Drinking Water Standards by the Advisory Committee. While the standards are not directly applicable to streams serving as sources of domestic water supply, they are applicable indirectly for a number of constituents which are unaffected or are only partially removed by conventional water treatment methods.

Bacon (18) presented a discussion on relation of water quality criteria to beneficial water uses. He pointed out that any use of water results in some change in quality. He suggested that criteria should be designed to permit the maximum beneficial uses of water, including that for waste disposal. Illustrations of water quality criteria are given for specific purposes such as irrigation, bathing, and fisheries, and for general use.

The Ohio River Valley Water Sanitation Commission's Aquatic Life Advisory Committee (17) published the third in a series of reports on water quality criteria for aquatic life. The Committee concluded that it was impractical to establish criteria for iron and manganese because so many other factors such as temperature, pH, hardness, and DO affect the toxicity of these compounds to aquatic life. They recommended the toxicity of wastes containing these materials be determined in specific situations by bioassay. For cyanides the Committee recommended a limit of 0.025 mg/l, but suggested that bio-assays would be helpful in any specific situation. A limit of 0.05 mg/l was recommended for phenolic substances with the warning that further research might indicate the necessity for a lower value. Although various investigators have concluded that detergents do not present a toxicity problem, it has been reported that as little as 0.2 mg/l has been found to be lethal. The Committee concluded that available information is inadequate to justify selection of a limiting value. Selection of criteria for radioactive contaminants presents a difficult problem. The MPC of 8×10^{-7} μc/ml for $Sr^{90} - Y^{90}$ in drinking water is adequate to permit safe use of fish for food. Some hazard from eating fish might result if the drinking water MPC for $CS^{137} - Ba^{137}$ were used. The presence of other radionuclides, which accumulate in fish muscle, at levels well below their MPC's for drinking water could produce definite hazards in consumption of fish for food. More precise knowledge of accumulations of particular radionuclides in fish is needed.

Abatement and Control

The National Conference on Water Pollution (11) (12) produced essential

agreement among spokesmen for government, industry, and citizen groups on several basic issues. These included recognition of the need to (*a*) retain present approaches to detection, abatement, research, and control of pollution but to expand each; (*b*) step up public information and education on the problem; (*c*) leave control to the states using federal authority where the states are unable or unwilling to act; (*d*) modernize state laws and control agencies; (*e*) speed municipal treatment plant construction and consider tax incentives for industrial waste treatment works; and (*f*) expand research and increase federal activity and support in this area.

At its 1960 annual meeting the Board of Control of the Water Pollution Control Federation adopted a statement of policy regarding nation-wide pollution problems (23). A 13-point pollution control philosophy was put forth as being necessary to assure the conservation and protection of the nation's water resources.

Water pollution control was described by Hollis (96) as a major instrument in water resource conservation. Major obstacles to meeting future water resource needs were considered to be the present inadequate rate of expenditure for treatment plant construction, insufficient stream quality data, and a lack of scientific research. Specific areas of research needs are the development of new pollution parameters and new treatment methods and the evaluation of public health and economic effects of pollution. Adams (3) reached similar conclusions regarding the inability of waste treatment as it is known today to be relied on to recreate the water resources reserve that will be needed in the future. Improvement in water conservation by industry was also considered necessary.

Substantial progress in pollution abatement was achieved with voter approval of bond issues of $15 million in St. Louis, Mo. (13), $75 million in Kansas City, Mo., $15 million in Kansas City, Kans., $10.7 million in Omaha, Nebr., and $2.8 million in North Kansas City, Mo. (14). Each of these communities was the subject of federal enforcement proceedings under Section 8 of Public Law 660. Sioux City, Iowa, and St. Joseph, Mo., are also included in this enforcement action. The latter presently faces court action for failure to comply with the abatement schedule adopted. In nation-wide November elections, of $215 million in bond proposals for sewers and waste treatment, 94 per cent were approved by the voters.

The metropolitan-wide approach to the solution of common sewage treatment problems for a fast growing area was demonstrated in the approval of a $28 million project to prevent the discharge of sewage effluent to the Potomac River near Chantilly, Va. (15). This plan complied with the Potomac River Commission policy to prevent all discharges above the District of Columbia water supply intake.

Activities and accomplishments of the Red River Compact were presented by Beckman *et al.* (22). The major problem in this basin, which includes areas in Arkansas, Louisiana, Oklahoma, Texas, and New Mexico, is poor mineral quality due to natural and man-made pollution. Oil field brines are the principal man-made source and the degree of its control achieved in the Ouachita River tributary was considered encouraging. Possible methods for control of natural pollution from salt springs and gypsum deposits were proposed.

Studies of the acid mine drainage pollution problem have resulted in several proposed methods for control (92) (171) (40). Prevention of contact of drainage waters with sulfuritic materials in open pit mines is suggested. Diversion of surface waters from the mine workings, the use of pipes rather than ditches to speed water movement, removal and burial of sulfuritic mate-

rial, and other control methods are also recommended.

Hull and Carbaugh (99) reported progress on an investigation of stream pollution abatement through augmentation of low stream flows. Legal and economic aspects are being studied in addition to technical evaluations. The principal technical problem being studied is the relation between stream flow and organic pollution. Analytical techniques have been developed to allow rapid computation of stream flow requirements.

Effects on Water Supply

Reports of synthetic detergent pollution of ground waters continue to increase. Deluty (50) tells of an incident in Rhode Island due to private sewage disposal systems, and Newell and Almquist (140) report one due to wastes from an industrial lagoon. Walton (185) summarizes incidents in 17 states related to household waste disposal practices and trouble in 9 states due to other causes. Netsch (139) discusses a similar problem in Europe due to lagooning of laundry wastes.

The American Association of Soap and Glycerine Producers Research Steering Committee (6) gives information on toxicity studies of ABS. Judging from two-year studies in rats the material is not highly toxic and other objectionable characteristics would cause ABS polluted water to be rejected at concentrations appreciably lower than those which would be physiologically damaging.

Cohen *et al.* (38) studied the effect of synthetic detergents on water coagulation with ferric sulfate. Their results were similar to those found with alum. The surface active agents caused no problem at concentrations up to 32 mg/l but sodium tripolyphosphate interfered with coagulation at concentrations as low as 0.1 mg/l. This polyphosphate interference is more noticeable with iron salts than with alum. Activated carbon at high doses removed the detergents. Nowacki (142) reports on removal of detergents from water.

Reploh and Küstermann (154) studied the interference of organic matter on coagulation with iron salts. Soluble plant cell substances affected coagulation adversely.

Taste and odor problems in the United States are discussed by Sigworth (162) based on answers to questionnaires sent to water works officials. Troubles attributed to sewage and industrial wastes were less prominent than troubles attributed to algae and decaying vegetation. The relative success of various treatment methods is summarized. Middleton (131) discusses various causes of taste and odor and the need for odor measurement at water plants.

Kinney (114) reports on studies of taste and odor problems at the Beaver Falls, Pa., water plant. Although phenol was almost always present other materials were also important contributors to the problem. Hartung (89) discusses taste and odor problems on the Missouri River and the control methods used by the St. Louis County Water Company. Tastes and odors due to hydrocarbons, toxicity of certain hydrocarbons, and treatment methods for their removal are discussed by van Beneden (182). Buydens (30) summarizes problems arising from pollution by petroleum industry wastes. Klotter and Neussel (122) discuss ground water pollution from oil well residues and the control of pollution of surface and ground water by oil was the subject of a symposium by the European Federation for the Protection of Waters (60). Zimmermann (200) and Zimmermann *et al.* (201), also discuss the problems of oil and tar products and water supplies.

Gabrilevskaya and Rubleva (71) report on studies of the toxic and organoleptic effects of wastes from manu-

facture of diphenylpropane. They suggest that the organoleptic effects would be dominant.

Pesticides and their significance in water supplies are discussed generally by Woodward (198). Cohen *et al.* (39) report on studies of the treatment of water for removal of fish poisons.

The threat to water supplies due to barging of toxic chemicals on the Ohio River is pointed up by an incident in which a damaged and leaking barge carrying ethyl benzene was beached nine miles above a water intake and contaminated the supply (16).

A number of papers (66) (151) (175) (176) (190) discuss in more or less general terms the effects of sewage and industrial wastes on water supplies and the need for pollution abatement.

Wilson (193) in England, and Frisch and Kunin (65) in this country, discuss the fouling of anion exchange resins by organic acids, particularly humic acids, which diffuse into resin pores and are not removed by normal regeneration. Strong brines help to remove some of the material.

The American Water Works Association Task Group on Underground Waste Disposal and Ground Water Contamination (8) discussed the need for guides in evaluating disposal techniques and detecting unsatisfactory practices. Goncharuk (81) suggests limits on daily waste discharges per unit length of pipe in underground waste disposal to guard against ground water pollution. The question of the possible effects of fertilizers on mineral quality of ground water is discussed by Morette (134). A 20-yr study of composition trends in specific ground waters provided no evidence of harmful effects by fertilizers except for a possible but not substantiated increase in nitrates.

The Water Supply Committee of the American Public Health Association (7) urges extensive research on chemical contaminants and on methods of detection and identification.

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OVERFLOWS FROM COMBINED SEWERS IN WASHINGTON, D. C.

George J. Moorehead

Like many comparable cities, Washington, D. C., is served in part by a large network of old and inadequate combined-type sewerage facilities that discharge (or overflow) a polluting mixture of sanitary sewage and stormwater runoff into the local streams and the Potomac River during each nominal rainfall. Overflows of sanitary sewage sometimes occur during hot dry weather.

The very presence of pollution (and the visible evidence of pollution) along the waterfront of any river city is certainly undesirable. The existence of such in the heart of the Nation's Capital, where visitors from all over the world are always present, is extremely offensive.

To fully evaluate the problem and to continue efforts to abate pollution in the nearby watercourses, a special study was initiated late in 1958. This study was designed to produce a dependable engineering estimate of that percentage of sanitary sewage flow, originating in the combined sewer system drainage area of the District of Columbia, which is lost to the adjoining rivers and streams through combined-system stormwater overflows.

The purpose of this paper is to present a brief summary of the historical circumstances and events leading up to the study, to describe the study project in general, and to set forth the findings and remedial recommendations, insofar as they may be of interest and value to others.

As is the case in most engineering investigations, the limiting factors of time and financing were to some extent prominent throughout the study. It is felt, however, that it would have required much more time and money to accomplish any appreciable further refinements of the findings of the investigation.

Historical

The site of the District of Columbia, as approved by George Washington, lies largely along the "Y" formed by the junction of the Anacostia and Potomac Rivers (Figure 1).

Although all of the area set aside by Congress (in 1790) for the establishment of a federal city comprised the original District of Columbia, the new capital city, as it was developed on the Maryland side of the Potomac River, was designated as the City of Washington. Retrocession of the land on the Virginia side of the Potomac (in 1846) reduced the District of Columbia to its present area on the north, or Maryland side of the river. Today, however, the city development extends over the entire area. Thus, the District of Columbia and the City of Washington are one and the same, generally referred to geographically as "Washington, D. C.," but politically and legally as "The District of Columbia."

George J. Moorehead is Chief of the Planning Branch, Office of Planning, Design and Engineering, Department of Sanitary Engineering, District of Columbia. *This paper was presented at the 33rd Annual Meeting of the Water Pollution Control Federation in Philadelphia, Pa., October 2–6, 1960.*

FIGURE 1.—The Washington Metropolitan area.

The city extends 11 miles along the northeasterly side of the Potomac and straddles the Anacostia for 6 miles. The average annual flow of the Potomac is 7,500 mgd, whereas the Anacostia averages 100 mgd.

The older portion of the city, which comprises the area served by combined sewers and is therefore the area of main concern in this discussion, rises gradually from the confluence of the Potomac and Anacostia Rivers to the encircling hills, and was originally drained by several sizeable streams discharging to these two rivers.

The land area of the city is approximately 61 sq miles. The water area, including the adjacent portion of the Potomac River within the city limits, constitutes some 7 sq miles.

The 1960 population, within the city limits, is reported by the U. S. Census Bureau to be 746,958.

The city, being largely made up of Government offices, public buildings, and related activities, has such a limited amount of industry that problems of industrial wastes have been relatively minor.

The total sanitary sewage flow averages about 200 mgd, of which approximately 50 mgd come from Maryland suburban areas beyond the city limits.

The U. S. Congress, the District's governing body, in 1916 authorized the discharging of existing and future upstream, adjacent, Maryland sewers into the sewer system of the District of Columbia, in order to protect the streams flowing through the District from pollution. At the same time, Congress authorized the Commissioners of

the District of Columbia to enter into agreements with the proper Maryland authorities regarding terms and conditions. With some mutually acceptable revisions from time to time, the general arrangements have worked advantageously for both parties from the very beginning. Then, in 1958, Congress enacted similar legislation regarding the sewerage facilities of adjacent Virginia areas upstream of the District of Columbia. Negotiations with the proper authorities in Virginia are now in progress.

Metropolitan Area

Montgomery and Prince Georges Counties, on the Maryland side of the Potomac River, along with Arlington and Fairfax Counties and the cities of Alexandria and Falls Church, on the Virginia side of the river, with the District of Columbia at the center, constitute what is known by the U. S. Census Bureau as the Washington Metropolitan Area. This represents about 980 sq miles in Maryland, and some 450 sq miles in Virginia.

According to the 1960 Census, the total population of the Metropolitan Area, including the District of Columbia, is approximately 1,969,000.

By the year 2000 it is expected that about 450 sq miles of the Maryland area and 225 sq miles of the Virginia area will be tributary to the District of Columbia sewage treatment plant, with an average sewage flow from the entire area, including the District of Columbia, of 350 mgd.

The 675 sq miles in Maryland and Virginia and about one-half of the 61 sq miles (the newer and outlying residential area) of the District of Columbia are now, or will be, served by separate-system collecting sewers, with no built-in overflows to the watercourses. Under the prevailing plumbing codes, only token amounts of stormwater (through window wells, limited areaway drains, etc.) are admitted to the sanitary lines in separate-system service areas. No stream pollution contributions are expected from these areas.

Combined-Sewer System

It is the remaining part of the District of Columbia, the older and "downtown" sections of the city which are served by combined-system collecting sewers, with stormwater overflows to the streams and rivers, that has presented a serious problem. This was the area of interest in the recent investigation (Figure 2).

The installation of culverts and drains to confine the natural streams and to accelerate stormwater runoff from the streets of Washington began about 1810. This marked the beginning of the existing "downtown" sewer system.

In 1840 spring and well water was first piped into a few houses with interior plumbing to produce the city's first waterborne sewage wastes, which in turn were discharged to the culverts, and thus a combined sewer system, without plan or design, had its modest, unnoticed beginning.

With the introduction of the Potomac River water supply in 1859, and a population surge promoted by the Civil War, the combined sewer system, discharging to the nearest watercourses, "just grew up."

The original culverts and storm drains were haphazardly connected together in such a fashion that by 1875 a combined-system sewer network serving the downtown area, with convenient discharges to the nearest watercourses, was well established.

By 1889, however, the creeks and streams, and particularly the marshes in front of the city, had become so foul and polluted that President Benjamin Harrison, under authority of an act of Congress, appointed a Board of Engineers to study the sewerage problem in the District of Columbia. The Board

reported in June 1890, recommending a plan whereby all of the dry-weather flows would be discharged into interceptor sewers and routed through an outfall sewer into the deep water of the Potomac River below the city. The plan was adopted and served satisfactorily until about 1920, when it became evident that the city would soon have to treat its sewage. A primary treatment plant was installed in 1938, and enlarged and extended in 1958 to provide secondary treatment.

Even though the 1890 Board of Engineers recommended against extension of the combined-system into new areas, it was not until the early 1920's, when approximately one-half of the city had been at least partially sewered on the combined-system basis, that a switch to separate-system service for all new areas was adopted.

At present, 12,250 sewage-producing acres of the older and "congested" sections of the city are served by combined sewers. As a part of this combined system there are 86 permanent, built-in stormwater overflows to the watercourses (Figure 3). These overflows are likely to function with each nominal shower of rainfall. Some discharge as many as 40 or 50 times a year; others operate only 2 or 3 times each year, depending on the drainage area characteristics and the local sewer and intereceptor capacities.

Washington, a city of wide streets and numerous parks, had a very low

FIGURE 2.—Combined-system service area.

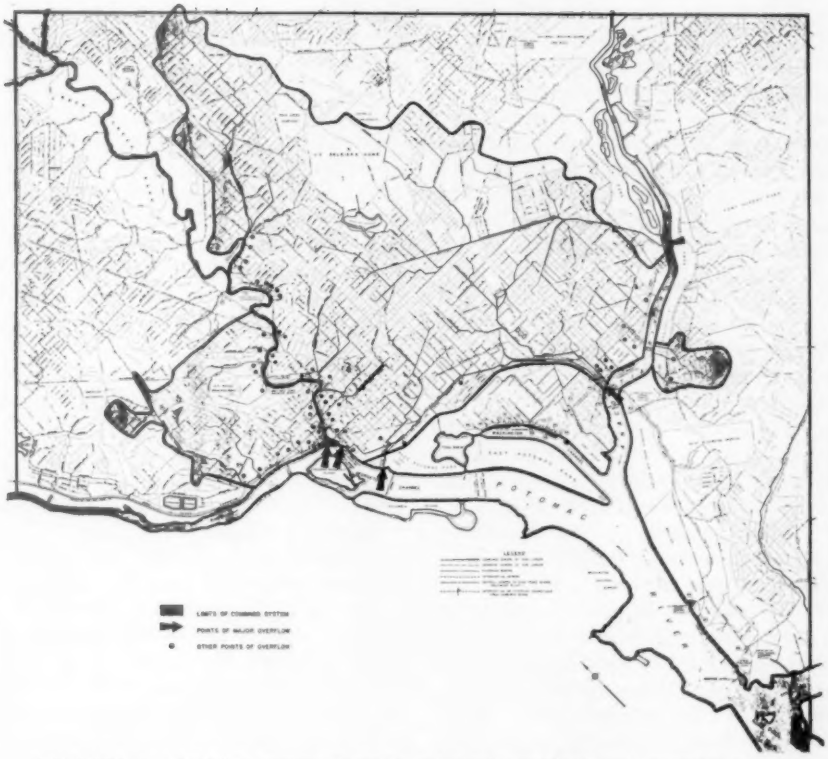


FIGURE 3.—Existing system showing principal combined and separate sewers.

rainfall runoff coefficient at the time the original combined sewer system was installed. But as more and more buildings were erected, street pavings grew wider and wider, and in recent decades, as parking areas have been paved, the rainfall runoff rate has increased to such an extent that practically all of the stormwater facilities in the old city area are inadequate by today's standards.

Under the present regulations, all roof leaders, areaway drains, etc., in the combined-system areas are connected into the combined sewers; even though some of the existing sewers are 20 ft or more in diameter, a deficiency still prevails in both interceptor and trunk sewer capacities throughout the city.

A complicating condition that had to be dealt with in the study was the fact that all of the main interceptor sewers which receive the dry-weather flows from the combined-system drainage areas also serve as transmission lines to convey the upstream sanitary sewage, collected from the separate-system areas within and beyond the District, through the combined-system area, to the sewage treatment plant downstream from the city. One phase of the present planning program is to segregate these interceptor services. In general, it is proposed to provide the necessary relief in the form of new interceptors (transmission lines) for the upstream separate-system sanitary sewers, and leave the existing interceptors to serve only the combined-system areas.

Then too, practically all of the existing interceptor lines are urgently in

need of substantial relief. This situation has a tremendous effect on the operation of the combined-system overflows. Now because of the inadequate, overloaded system, and the presence of large amounts of air-conditioning cooling water, a few of the stormwater overflows discharge raw sanitary sewage into the rivers on hot summer days during dry-weather peak flows.

Types of Overflow

The 86 stormwater overflows from the combined system sewers to the adjacent watercourses are, in general, classified into three types. First, and most important in the system are the mechanically-operated shear gates with floats, controlled from the liquid level in the interceptor sewers (Figure 4). This particular type has a sanitary (dry-weather flow) take-off that is designed to admit the maximum amount of flow into the interceptor by throttling the connection between the interceptor and the combined sewer in such a way as to utilize all of the available capacity in the interceptor. When the maximum interceptor capacity is reached, the diversion connection is closed and all of the combined-system flow is discharged to the receiving stream.

The second type also has mechanically-operated shear gates, with floats similar to the first type, except that the operation is controlled by the liquid level in the combined-system sewer without respect to the available interceptor capacity (Figure 5). These gates throttle and close as the liquid level in the combined sewer rises, and open again when the depth of flow in the combined sewer decreases to a predetermined level, representing from one to many times the peak dry-weather sanitary flow.

The third type, constituting by far the largest number, is of the fixed-orifice type, requiring no mechanical equipment (Figure 6). This method of diversion is accomplished with a low dam or sump built into the combined sewer. On the upstream side of the dam, or within the sump, there is a relatively small (6- to 15-in. pipe) connection leading, uncontrolled, to the interceptor. When the combined flow is less than that required to overflow the low dam or sump, all of the flow is

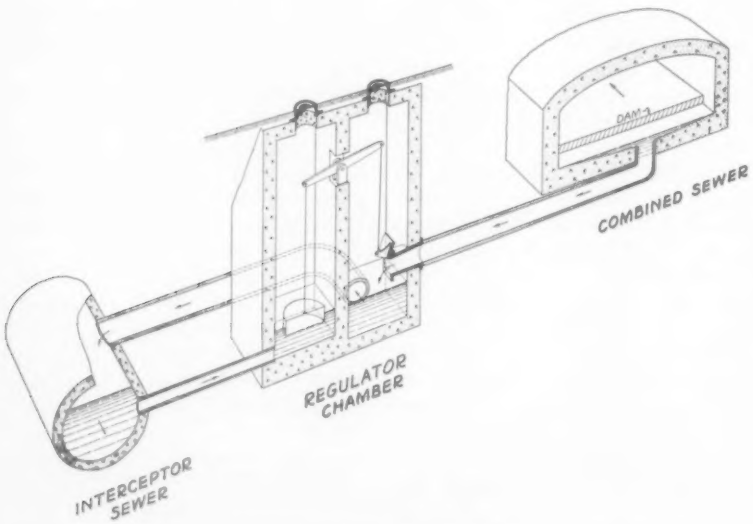


FIGURE 4.—Type I regulator.

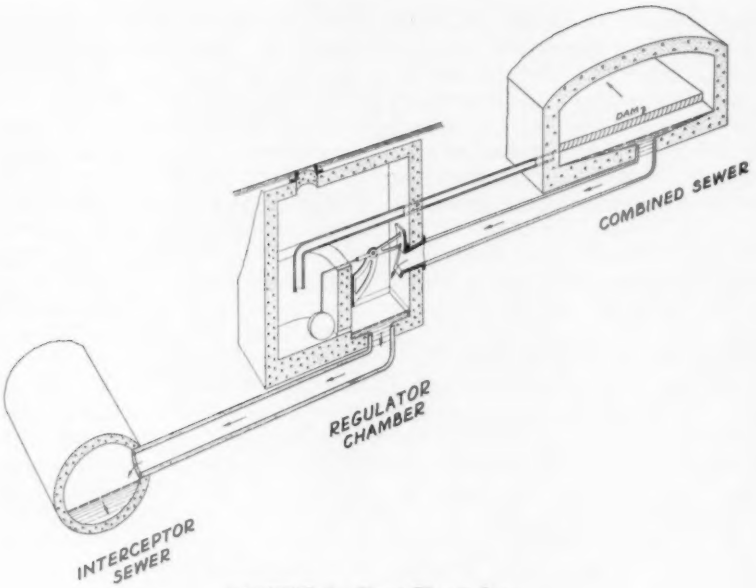


FIGURE 5.—Type II regulator.

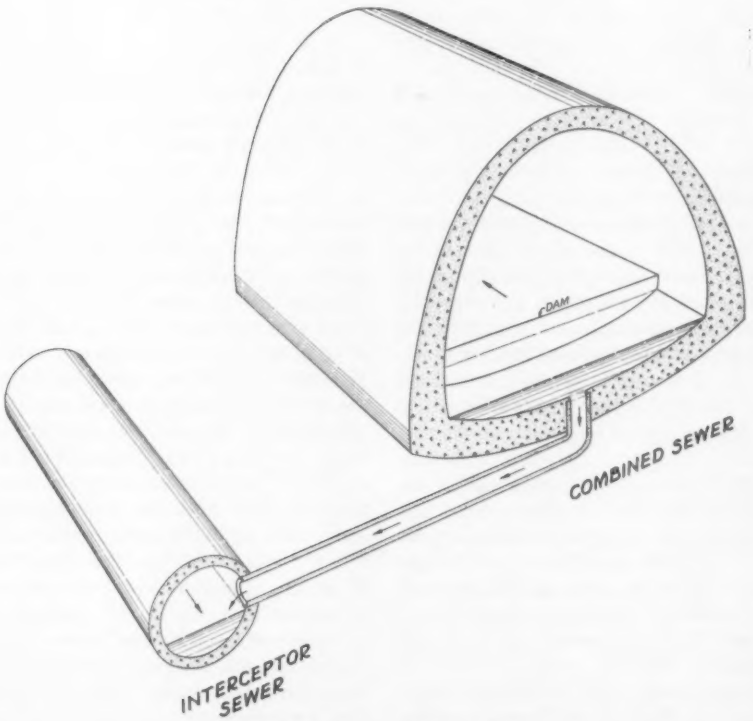


FIGURE 6.—Type III regulator.

diverted into the interceptor, provided there is sufficient interceptor capacity available. Excessive flows, over-topping the low dam or sump, discharge to the receiving stream. The interceptor connection continues to operate as long as capacity is available. At times the interceptor, flowing under pressure, will reverse the direction of flow in the sanitary take-off connection and relieve itself by discharging into the combined-system stormwater overflow.

Recent Comprehensive Studies

By the early 1930's, it became quite evident that the city had outgrown and extended far beyond the limits of the 1890 Board of Engineers' forecasts and recommendations. Although many localized studies were made from time to time, it was not until after a general reorganization of the entire District Government in 1953 that arrangements were made for a complete review of the sewerage facilities, and a new long-range over-all planning program was instituted.

Another Board of Engineers (Frank A. Marston, *Chairman*, Samuel A. Greeley, and Gustav J. Requardt) was engaged and presented the assignment as of June 29, 1954.

In order to relieve the newly-formed Board of the tremendous amount of necessary preliminary investigation and analysis of the existing sewerage facilities, a consulting engineering firm was employed to work under the direction of the Board to compile such data as the Board deemed pertinent to form a basis for its studies and recommendations.

Thus, the scope of the Board's assignment and the consultant's investigation was to analyze the existing facilities, related functions and potentialities, and to recommend a long-range over-all planning program, forecasting all the apparent requirements to the year 2000.

In accordance with the Board's suggestion, the District (between October 1955 and March 1956) installed nine automatic, continuous-recording-type, depth-of-flow gages at various critical stormwater overflow points throughout the combined-system service area to supplement existing cup-gage data.

As early as 1922 many cup-type, maximum depth-of-flow gages were in service within the system. These gages consisted of small sheetmetal cups attached at 4- to 6-in. intervals on vertical rods inserted in small standpipes mounted on the inside of existing manholes. After each major storm the cups were inspected and the elevation of the highest cup containing liquid was recorded as being the maximum depth of flow during the storm. This type of gage served only as an indication of the peak amount of overcharging within the system, without respect to duration or magnitude of the stormwater flows.

The Board of Engineers, among other things, considered converting all of the existing combined-sewer system into a separate system of sewers by building a complete new network of sanitary collecting lines and connecting them into the existing interceptors and then into the sewage treatment plant. Aside from the fact that the existing combined-system sewers would still be inadequate as stormwater lines, complete separation of the system by an early date was found to be economically impractical. A new sanitary network (and the necessary local plumbing alterations) was estimated to cost approximately $300 million. To complete the street work alone would require 20 construction crews, each working full time for 20 years. Thus, The Board selected a compromise program (known as Project C) whereby some separation work was recommended, but the majority of the existing stormwater overflows on the combined system were scheduled to remain in limited, acceptable service (Figure 7).

Because the ultimate aim is to protect the watercourses from pollution, and because most of the combined-sys-

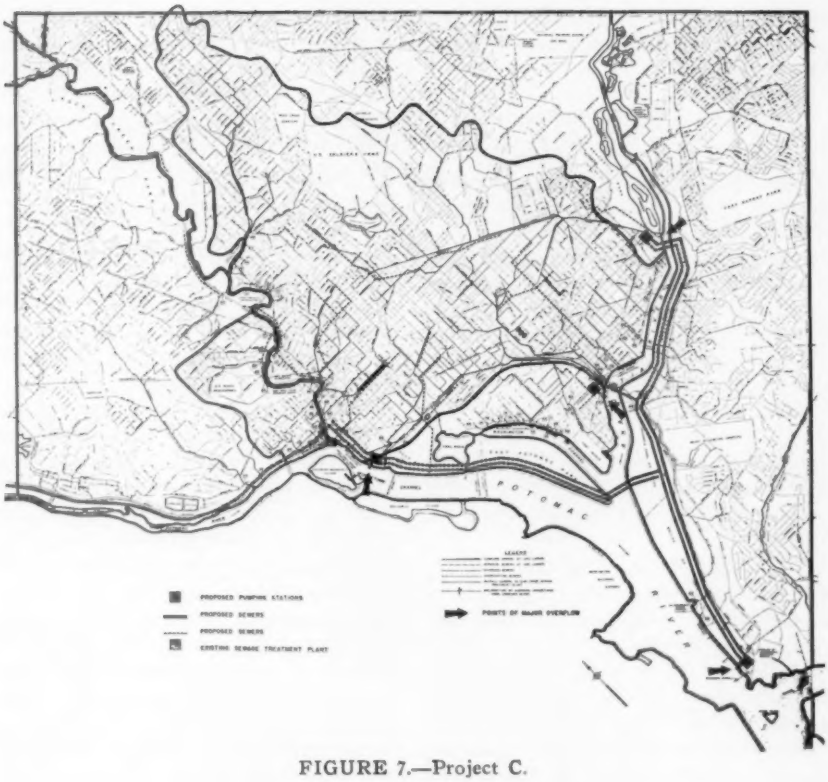


FIGURE 7.—Project C.

tem stormwater overflows are scheduled to remain in service for extended periods into the future, a detailed study and analysis of the intended functions and actual operations of each overflow structure was considered necessary.

With this in mind, it was decided to make an analysis and volumetric study of all combined-system overflows and overflow structures, and to make a prediction of expected future performances.

The District installed several additional recording gages and made such spot-check depth-of-flow measurements as were practical to assist in obtaining basic data. About 20 recording-type gages are now in continuous service.

On request, the consulting engineers assigned the same key personnel to direct and conduct the study as had previously been employed in the preparation of both the preliminary investigation and the Board of Engineers' report. Thus, little time was consumed in acquiring background knowledge of the drainage areas and the designs and operations of the various overflow structures.

Because the overflows to the watercourses are directly related to the local rainfalls over the tributary drainage areas, the first steps in the study were to translate the recorded rainfall data into depth-duration values and then correlate the rainfalls with the recorded stormwater overflows on a frequency and volumetric basis.

The next phase of the project produced an estimate of the amounts of dry-weather sanitary sewage originating in the various drainage areas, and

compared these quantities with the total discharges of combined sewage through the overflows.

Results of Studies

On completion of the supplementary study, the consultants reported that the amount of sanitary sewage generated within the combined sewer system drainage areas for the years 1956, 1957, and 1958, was estimated to average 109.4 mgd, of which 3.3 per cent (an average of 3.6 mgd) was lost through the stormwater overflows to the watercourses.

It is interesting to note that of the 3.3 per cent escaping to the watercourses, 0.3 per cent was lost during dry weather because of inadequate capacities in the existing sewerage facilities.

Even though many of the overflow structures are scheduled to continue in service for extended periods, on completion of the installation of relief facilities and the modification of the existing sewerage system, as recommended by the Board of Engineers, the overflow of combined-system sanitary sewage during rainstorms is estimated to be reduced to an average of 376,000 gpd, or 0.4 per cent of the total sanitary flow expected to be generated in the combined-system drainage area. No dry-weather overflows are anticipated.

In a companion paper (see page 721), C. Frank Johnson, engineer in charge of the study project for the consultants and also Engineer Director for the Board of Engineers, gives a more detailed description of the procedure and the methods employed to arrive at the final conclusions.

Although the present overflows to the watercourses are considered to be excessive and some evidence of pollution is present along the rivers and streams, it is believed that when the program outlined by the Board of Engineers and refined by subsequent studies (Project C) is completed the local watercourses will be acceptable for boating and fishing, and in some upstream areas swimming may be permitted.

The study has pinpointed the source and magnitude of the District's major stream pollution problem; the Board of Engineers has recommended a stream pollution abatement program; the Commissioners of the District of Columbia have approved and accepted, with some refinements, the Board's program; and the Department of Sanitary Engineering is expediting construction of the proposed facilities as rapidly as funds become available.

Thus, it is hoped and planned to have in the near future a reasonably clean and beautiful Potomac flowing past the Nation's Capital City.

OPERATOR'S MANUAL CORRECTIONS

The serialization of the Federation Manual of Practice No. 11, "Operation of Sewage Treatment Plants," was completed in the June Journal.

In order for the Committee to consider reader comments prior to final printing as a bound manual, those comments must be in the Federation office by August 15. The Committee will appreciate any evaluation by that date.

EQUIPMENT, METHODS, AND RESULTS FROM WASHINGTON, D. C., COMBINED SEWER OVERFLOW STUDIES

C. Frank Johnson

For many years, engineers and public officials everywhere have rightly deplored the overflow of sanitary sewage from combined sewers to the streams during times of rainstorms. However, in most cases little detailed study has been made to throw light on the problem.

Conditions at Washington, D. C., that resulted in such a study being made for that city, as well as the highlights of the study and its findings, have been described in the preceding paper (see page 711).

The purpose of this discussion is to give additional comments and details regarding the recent investigations of overflows from the combined sewers of Washington.

Important factors in connection with such overflows are their frequency, duration, and the rate or quantity of overflow. These features were included in the studies at Washington. Another important factor is the strength or characteristics of the overflowing liquid in terms of the usual analytical parameters. This factor was not included in the Washington study in detail, although some consideration was given to it. It is hoped that future studies will include this factor in detail.

C. Frank Johnson is Senior Engineer, Metcalf & Eddy, Boston, Mass.

This paper was presented at the 33rd Annual Meeting of the Water Pollution Control Federation in Philadelphia, Pa., October 2–6, 1960.

Overflow Gages

As previously mentioned (see preceding paper), nine overflow gages were placed initially at selected locations where conditions were suitable for the observations. Only eight of the gages were utilized for this study, however, and several additional depth-of-flow gages placed in various sewers later were for purposes other than the overflow study. The gages were installed, operated, and maintained by the Department of Sanitary Engineering of the District of Columbia.

Inasmuch as the existing overflow structures were not designed or constructed with the idea of gaging the overflows, conditions at some of them were not very suitable for gages, and a careful study of the several overflow structures was necessary to determine suitable locations. It was desired to place the gages on the sewers which were thought to be the worst offenders with respect to overflow of sewage to the streams. Physical conditions at the various locations varied widely, with the result that the hydraulic computations of the overflow quantities were quite varied in nature and sometimes rather complicated.

The gages were so installed as to provide continuous chart records of the respective sewage-surface elevations just upstream of the overflow weirs or dams. The zero of each gage was placed at a convenient elevation, usually a few inches below the crest of

the overflow weir or dam, inasmuch as it was desired to gage the overflow only.

The gages had a range of 10 ft, this being sufficient to include the needed variation in observed overflow depths.

Six of the eight gages are of the diaphragm box type, which utilizes a submerged pressure-sensitive bell (diaphragm box) placed in the sewer.

Two of the eight gages are of the continuous purge, bubbler type, which utilizes hydrostatic pressure at the point of measurement to determine the sewage level.

In both types of gages the recording instrument is placed at a nearby convenient location, preferably aboveground. Originally, some of the recorders were placed in dry manholes constructed for the purpose, but these instruments are gradually being moved to housings aboveground, because of operating difficulties below ground.

First Phase of Study

The two phases of the study of overflows are mentioned by Moorehead (see page 711). The first phase was concluded in February 1957, when the Board of Engineers made its report.

The purpose of this portion of the study was to obtain a guide or yardstick for the use of the Board of Engineers in devising a comprehensive plan of improvements to the sewer system. Inasmuch as the overflow gages had been in place for only slightly longer than one year when the Board prepared its report, this portion of the overflow study was based on one year of records, from November 1, 1955, to October 31, 1956.

Dilution Factor

After studying various approaches to the problem, the Board of Engineers decided to use the so-called "dilution factor" as a guide in its study. This factor may be defined as the ratio of the capacity of the interceptor or interceptor connection to the annual average dry-weather flow which is being intercepted.

Criteria

In studying the frequency of overflows, it was necessary to adopt a criterion for counting the individual overflows. It was obvious that an interval of 1 hr, 2 hr, or even several hours, between successive overflows resulting from rainstorms would not give the result of two distinct overflows as if separated by a longer interval. It was decided to count successive overflows from rainstorms as only one occurrence except when there was an interval of 24 hr or more between overflows. A similar criterion was adopted for counting rainstorms. Dry-weather overflows occurring on successive days, however, were counted as separate occurrences.

In studying the duration of overflows, only the time of actual overflow to the streams was considered.

By the use of these criteria, the number and duration of all observed overflows were determined for study. Because the summer months are the more critical, certain overflow data were at first separated into summer months (May 1 to October 31) and winter months (November 1 to April 30).

Excessive Overflows

Table I gives a summary of all overflows where the number was considered to be excessive. These include dry-weather overflows, as well as those resulting from rainstorms.

The average number of overflows per month at the individual gage locations ranges from 5.0 to 16.8 during the summer months and from 3.8 to 4.7 during the winter months. Such frequencies are considered to be excessive.

In every instance the number of overflows during the summer months exceeded those occurring during the winter months. The duration of summer overflows similarly exceeded the

TABLE I.—Summary of Overflows to Streams Where Number was Excessive

Location, Gage No.	Dilution Factor*	Overflows in 6 Summer Months (May–Oct.)				Overflows in 6 Winter Months (Nov.–Apr.)			
		Number		Duration (hr)		Number		Duration (hr)	
		Total	Avg per Mo	Total	Avg per Mo	Total	Avg per Mo	Total	Avg per Mo
3	2.2	52	8.7	376	63	23	3.8	183	31
4	8.3†	30	5.0	179	30	26	4.3	166	28
5	1.3	61	10.2	340	57	24	4.0	228	38
6	2.0	32	5.3	144	24	25	4.2	157	26
7	1.9	101	16.8	660	110	28	4.7	191	32

* As used for first phase of study.

† Conditions somewhat obscure at this location; accuracy of dilution factor is questionable.

duration of winter overflows except for one location, where they were nearly the same.

At three of the gage locations, overflows of sewage occurred during dry weather, all during the months of May through September, as summarized in Table II.

These dry-weather overflows are, of course, especially undesirable, occurring during the summer months. The average duration of the overflows was long, ranging from 5.4 hr in one sewer to 11.5 hr in another. In each of the sewers, the frequency was high during certain months (from 13 to 20 times per month). This indicates that dry-weather overflows occurred on an average of from 3 to 5 days per week during these months.

TABLE II.—Summary of Overflows to Streams During Dry Weather

Location, Gage No.	Dry-Weather Overflows During 12 Months			Month	No. in Month
	Total No.	Duration (hr)			
		Total	Avg per Occurrence		
3	16	184	11.5	July	15
				Aug.	1
5	30	162	5.4	May	2
				June	13
				July	8
				Aug.	7
7	65	476	7.3	May	2
				June	16
				July	20
				Aug.	20
				Sept.	7

Frequency and Duration of Overflows

The frequencies of the observed overflows resulting from rainstorms, together with the corresponding computed dilution factors, were plotted (Figure 1) for the entire 12-month period. As would be expected, the frequency of overflows is low for the high dilution factors, and high for the low dilution factors.

Also plotted in Figure 1 are curves representing the result of hypothetical computations for the area tributary to gage No. 2 and for an area of 1,012 acres along the upper Potomac River. These two curves apply to conditions assumed for the year 2000, the year of design for the proposed sewerage improvements. They are fairly consistent with the observed values at the overflow gages.

Similar data showing the relation between the duration of overflows and the dilution factor are shown in Figure 2. The duration of overflows, like the frequency, is low for the high dilution factors, and high for the low dilution factors.

Figures 1 and 2 show clearly that the dilution factors for the existing

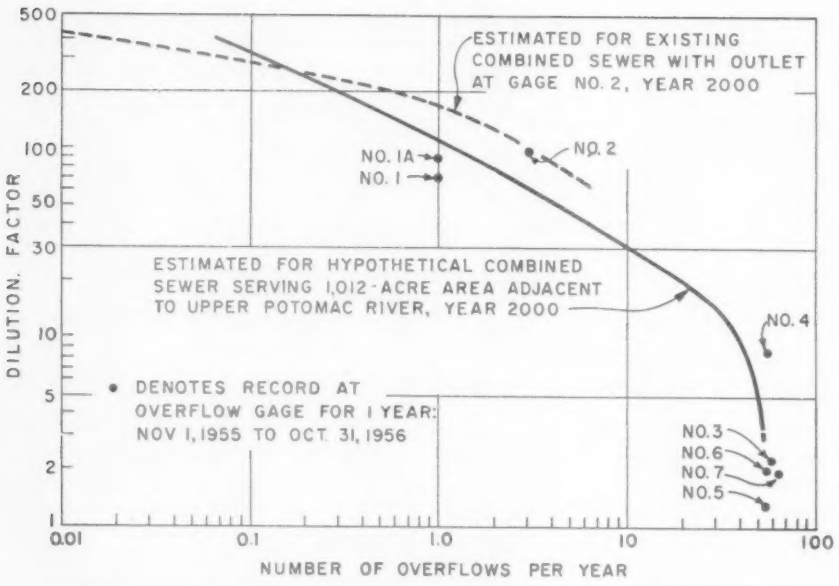


FIGURE 1.—Relation between frequency of overflows resulting from rainstorms and dilution factor.

interceptors are very low where excessive overflows were found. At four of the five locations of excessive overflows previously given in Tables I and II, the dilution factor ranges from 1.3 to 2.2. At the other location (gage No. 4) a higher dilution factor was computed, but there is some doubt as to its accuracy because of obscure local conditions at the site of the gage.

By contrast, the three locations having only from one to three overflows

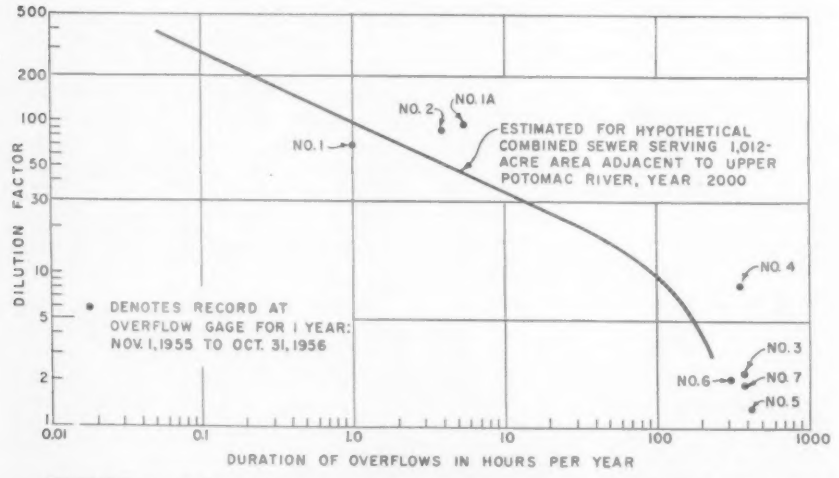


FIGURE 2.—Relation between duration of overflows resulting from rainstorms and dilution factor.

TABLE III.—Estimated Overflow Data for Combined Sewers Serving 1,012-Acre Area, Year 2000

Dilution Factor	Rainfall Intensity (in./hr)	Average No. of Overflows			Total Duration of Overflows (hr)		
		Summer	Winter	Year	Summer	Winter	Year
3	0.038	26	30	56	100	135	235
5	0.057	24	26	50	84	98	182
7	0.075	23	23	46	70	70	140
10	0.101	20	18	38	55	45	100
20	0.19	12	7	19	23	11	34
30	0.28	7	3	10	12	2	14

per year, with correspondingly short durations, are shown by Figures 1 and 2 to have very high dilution factors (69 to 95).

The detailed data used as a basis for portions of the curves of Figures 1 and 2 for the 1,012-acre area are given in Table III, which shows a rapid decrease in the number and duration of overflows, both summer and winter, as the dilution factor increases.

Dilution Factors Adopted for Design

After considering the data of Table III and making a study of the cost of typical interceptors designed on the basis of various dilution factors up to 30, the Board of Engineers adopted a dilution factor of 30 for use in areas along the Potomac River upstream of the mouth of Rock Creek. This represents the reach of the river where it is desired to improve the stream so that swimming, as well as boating, can be enjoyed.

The same dilution factor of 30 is to be used for combined sewers in the Rock Creek valley, inasmuch as this is a park area where pollution is to be reduced to a minimum.

For the portion of the Potomac River below the mouth of Rock Creek, and for the Anacostia River, a dilution factor of 5 was adopted. These reaches are tidal and it was considered impracticable to make them safe for swimming. The tidal motions of the water cause the pollution to remain in the river much longer than where there is a continuous downstream flow. These downstream reaches will satisfactorily assimilate without nuisance the resulting polluting matter discharged into them after the recommended improvements are made.

Second Phase of Study

The second phase of the study has extended from December 1958 to the present. It is concerned largely with the quantity of sanitary sewage which overflows to the rivers and with its percentage of the total amount of sanitary sewage. Also of concern is the percentage of time when overflows occur.

The primary purpose of this portion of the study is to obtain precise information on the quantity of overflow, for the further information and use of city officials and others in giving detailed consideration to the program of improvements recommended by the Board of Engineers. This information has been used in acquainting other officials, other agencies, and the public with the program of improvements. Also, precise information on quantities overflowing to the streams is needed for consideration of giving limited treatment to the overflowing liquid.

This phase of the study has been based on overflow gage records for the three calendar years of 1956, 1957, and 1958, using records for four of the overflow gages previously mentioned, plus certain records of overflows at, and adjacent to, the main sewage pumping station.

Rainfall

The rainfall record for the three years of 1956, 1957, and 1958 was studied first, to determine if typical stormwater overflow data probably could be expected from the overflow gage records for these years, and also to see what light might be thrown on stormwater runoff for low precipitation rates. The precipitation for the entire 3-yr period was 97 per cent of normal, so it was concluded that the total stormwater overflow for the period would be about normal. However, the precipitation varied somewhat for each of the three years, being 92, 87, and 113 per cent of normal, for the years 1956, 1957, and 1958, respectively.

Precipitation data for the summers and winters of the three-year period are given in Table IV. The summer precipitation was much below normal, whereas the winter precipitation was above. The total actual amount, however, was about the same for the two periods, resulting from the fact that normally the precipitation in the summer greatly exceeds that in the winter. Data on low precipitation rates will be referred to later.

Overflow Gages 3 and 6

The first and most extensive studies of overflows were made on the records for gages 3 and 6, representing the East Side Rock Creek diversion sewer and the Northeast boundary trunk sewer, respectively, inasmuch as they serve large areas and the overflow conditions are not too complicated. Principal characteristics of these two sewers are given in Table V, which shows that the two sewers are very similar. Together, they serve more than 7,100 acres, representing 58 per cent of the total area served by all of the combined sewers. However, there is one important difference not indicated by Table V. The East Side Rock Creek diversion sewer is an interceptor, serv-

TABLE IV.—Precipitation Data, United States Weather Bureau, City Office, 1956–8

Period	Normal Precip. (in.)	Average Precip. for 1956, 1957, 1958	
		Amount (in.)	Per Cent of Normal
Summer	23.26	20.11	86
Winter	18.18	20.21	111
Total for year	41.44	40.32	97

TABLE V.—Characteristics of East Side Rock Creek Diversion Sewer and Northeast Boundary Trunk Sewer, 1956–8

Item	East Side Rock Creek Diversion Sewer	Northeast Boundary Trunk Sewer
Overflow gage No.	3	6
Dilution factor	1.93	2.0
Tributary population	181,100	155,700
Tributary area (acres)	3,490	3,675
Avg coeff. of imperviousness	56	47
Time of concentration, minutes	71	50
Yearly avg dry-weather flow:		
cfs	33	36
cfs/acre	0.0095	0.0098

TABLE VI.—Results of Study for East Side Rock Creek Diversion Sewer and Northeast Boundary Trunk Sewer, 1956–8

(*a*) East Side Rock Creek Diversion Sewer

Time when overflow occurred (%)	5.15
Sanitary sewage overflowing (%)	1.68

(*b*) Northeast Boundary Trunk Sewer

Frequency of overflows (avg no./mo):	
Summers (6 mo each year)	4.50
Winters (6 mo each year)	4.44
Three years	4.47
Duration of overflows (avg hr/mo):	
Summers	23.9
Winters	39.7
Three years	31.8
Time when overflow occurred (%):	
Summers	3.25
Winters	5.48
Three years	4.36
Sanitary sewage overflowing (%):	
Summers	2.01
Winters	2.40
Three years	2.20

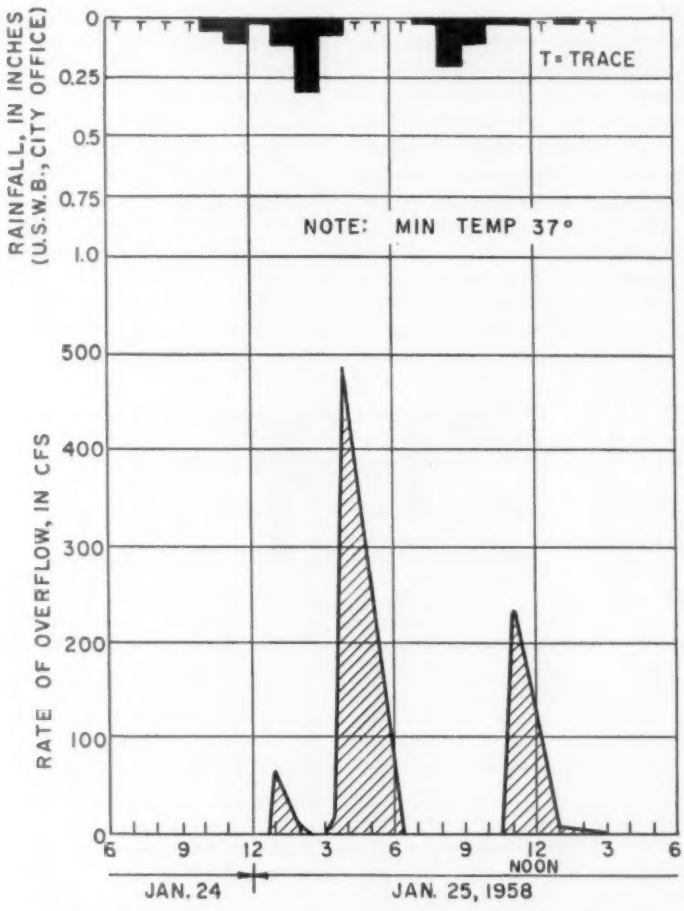


FIGURE 3.—Overflow from East Side Rock Creek diversion sewer on January 25, 1958 (overflow gage No. 3).

ing several combined sewers upstream of the gaging point, whereas the Northeast boundary trunk sewer is merely a combined sewer. The dilution factors for the connections to the diversion sewer are large (some as great as 100), with the result that it functions much as a combined sewer, especially for ordinary rainstorms.

The principal results of the study relating to overflows caused by rainstorms during 1956, 1957, and 1958 for these two sewers are given in Table VI (a partial study was made for one sewer and a complete study for the other). The over-all percentage of sanitary sewage overflowing from these two sewers, 1.68 and 2.20 per cent, respectively, is somewhat less than had been expected in the light of meager general information heretofore available relating to stormwater overflows.

The duration and percentage values of overflows for the winter period in the Northeast boundary trunk sewer are shown to be unexpectedly greater than corresponding values for the summer period. This is thought to be

the result, at least partially, of the unusual relative precipitation for the summers and winters of the 3-yr period, as indicated by Table IV, which shows that the summer precipitation was about the same in amount as that for the winter, rather than being greater, as is normal. The higher coefficient of runoff (usually assumed) for the winter months caused greater relative runoff, and therefore increased overflow, during the winter. Usually, the summer storms are more intense, tending to produce more runoff, but of shorter duration, tending to cause less overflow of sanitary sewage than if of longer duration.

Typical gaged overflows for the East Side Rock Creek diversion sewer are shown in Figures 3 and 4, together with the rainfall record for the period. Figure 3 shows winter (January) conditions; Figure 4 shows summer (August) conditions. The relation between time of rainfall and time of overflow, as well as between hourly amounts of rainfall and the rate of overflow, is indicated by these graphs.

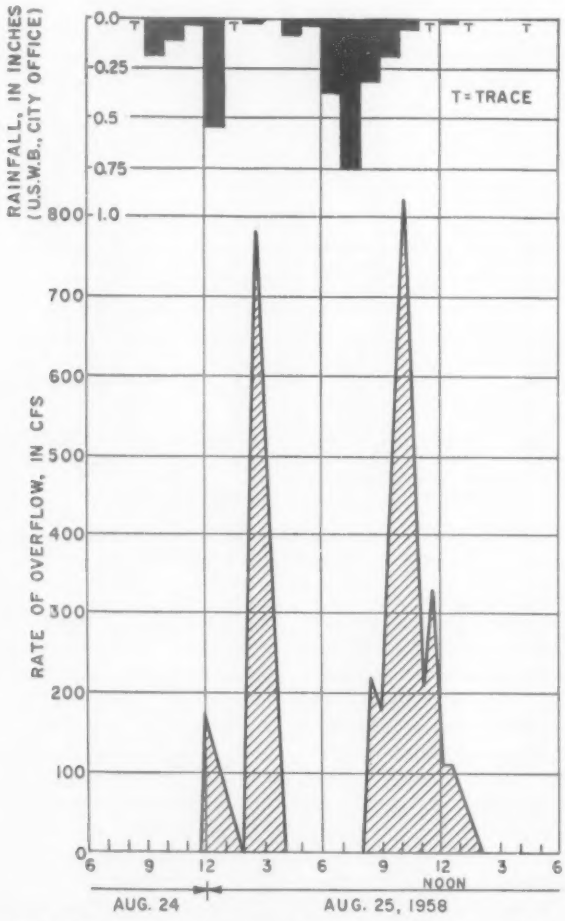


FIGURE 4.—Overflow from East Side Rock Creek diversion sewer on August 25, 1958 (overflow gage No. 3).

TABLE VII.—Estimated Overflows from East Side Rock Creek Diversion Sewer and Northeast Boundary Trunk Sewer, for Assumed Conditions

Dilution Factor	Sanitary Sewage Which Would Overflow as Result of Rainstorms (%)	
	East Side Rock Creek Diversion Sewer	Northeast Boundary Trunk Sewer
2	1.81	1.43
3	0.87	0.82
4	0.54	0.59
5	0.37	0.46
8	0.12	0.25

In connection with the time lag of somewhat more than 1 hr for the overflows shown in Figures 3 and 4, with respect to rainfall, the computed time of concentration for this sewer is 71 min (Table V).

In connection with the relation between the rate of rainfall and overflow, it was observed that the larger hourly rainfall in August (0.75 in. in 1 hr, maximum rainfall) produced less than proportionally larger overflow rates, as compared with the corresponding data for January (0.30 in. in 1 hr, maximum rainfall). In other words, the coefficient of runoff in August was less than in January, as would be expected.

However, the effect is modified by the fact that the East Side Rock Creek diversion sewer, an interceptor, is subject to several overflows at points upstream of the gage, especially for the more intense storms. This would tend to decrease the overflow effect at the gage of the heavier rainfall of August 25 as compared with that of January 25.

Overflow conditions in these two sewers were somewhat different than would be expected for redesigned connections to adequate interceptors. This is due to the construction and operation details of the structures, as well as to the inadequate existing interceptors. Computations were made of the quantities which would overflow as a result of rainstorms, based on the

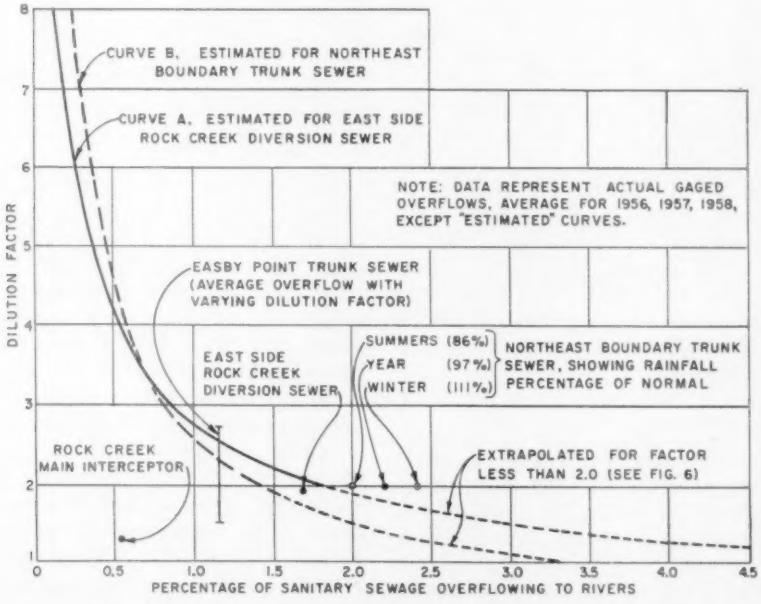


FIGURE 5.—Overflow from certain combined-sewer areas, resulting from rainstorms.

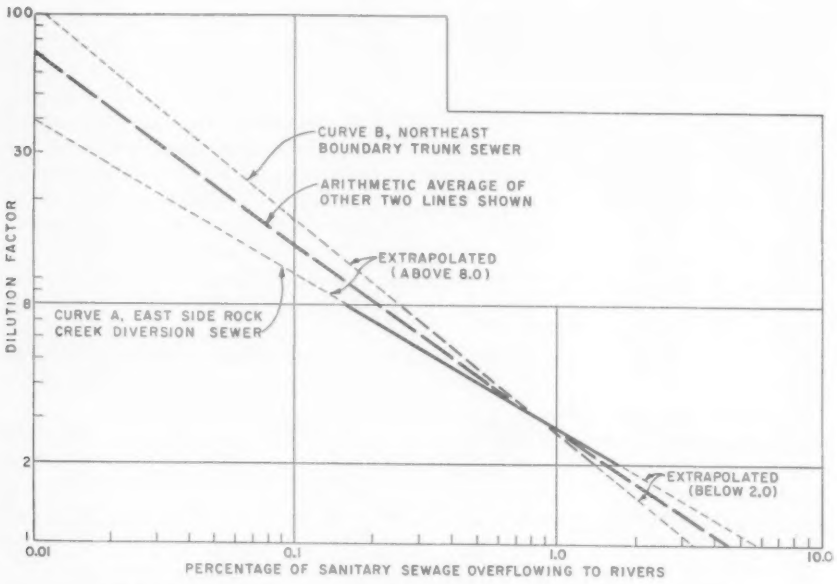


FIGURE 6.—Overflow from two sewers resulting from rainstorms.

actual gaged overflows during the 3-yr period, for such redesigned connections to adequate interceptors, using various dilution factors. The results (Table VII) are plotted in Figure 5 as Curves A and B, together with certain observed overflows for comparison. The two curves are so nearly the same that it was decided to use their arithmetic mean for computing the quantity of sanitary sewage overflow from other and smaller combined-sewer areas of the city, where no overflow gage records were available. Extrapolated values were used for dilution factors less than 2.0 and greater than 8.0 (Figure 6).

Total Overflow

Total quantities of sewage overflowing as a result of rainstorms were computed for the entire combined-system area, based on gage records, pumping station records, and the average line of Figure 6 for areas having no overflow records. The results are given in Table VIII.

Similar computations for dry-weather overflows were made for the combined sewers where gage records or pumping station records were available. The results are given in Table IX. The computations for dry-weather overflows could not include sewers where no overflow records are available, inasmuch as there is no basis for estimating assumed overflows during dry weather. However, it is thought that little or no dry-weather overflow occurred at the other sewers because they have fairly large dilution factors and because the occurrence of such overflows would surely have been the subject of complaints to District officials.

Data given in Tables VIII and IX are summarized in Table X, which shows an overflow of 3.02 per cent of the sanitary sewage resulting from rainstorms, for the combined-system areas. This percentage is somewhat higher than normally would be expected, because some of the sewage passes two, three, or even four overflow points in traversing the system of

TABLE VIII.—Overflows from Combined-System Areas Resulting from Rainstorms, 1956–8

Name of Sewer	Overflow Gage No.	Yearly Avg Dry-Weather Flow Subject to Overflow (mgd)	Dilution Factor	Sanitary Sewage Overflowed to Streams from Rainstorms		
				% of Time Overflow Occurred	% of Avg Dry-Weather Flow in Sewer	Yearly Avg Quantity Overflowed (mgd)
East Side Rock Creek diversion sewer	3	21.41	1.93*	5.15	1.68	0.36
Rock Creek main interceptor	5	20.00†	1.3	4.00	0.53	0.11
Northeast boundary trunk sewer	6	23.35	2.0	4.36	2.20	0.51
Easby Point trunk sewer	7	10.00	1.52 to 2.74*	4.31	1.17	0.12
Tiber Creek trunk sewer	—	18.20	—	6.75	6.75	1.23
Main sewage pumping station	—	45.75†	—	1.61	1.61	0.74
All other combined sewers	—	45.92	1.9 to 103.0	—	0.52	0.24
Total	—	109.4‡	—	—	3.02	3.31

* As revised for second phase of study; due in some instances to revisions in the sewers.

† Reduced value because of large quantities which overflow at upstream locations during rainstorms.

‡ Total dry-weather flow from all combined-system areas; not total of all previous values, because some sewage is subject to overflow at two or three places.

interceptors. Also, the overflow from the Tiber Creek trunk sewer (Table VIII) is abnormally great, being the result of normal manipulation of gate valves at the main sewage pumping station. If the values for this sewer were recomputed on a normal basis (that is, similar to the other sewers), the total overflow resulting from rainstorms would be reduced to somewhat less than 3 per cent.

An estimate also was made of the overflow of sanitary sewage originating in separate-system areas, inasmuch as some of this sewage passes the same overflow points as the sewage from

TABLE IX.—Overflows from Combined-System Areas During Dry Weather, 1956–8

Name of Sewer	Overflow Gage No.	Yearly Avg Dry-Weather Flow (mgd)	Sanitary Sewage Overflowed to Streams During Dry Weather		
			% of Time Overflow Occurred	% of Avg Dry-Weather Flow in Sewer	Yearly Avg Quantity Overflowed (mgd)
East Side Rock Creek diversion sewer	3	21.41	0.58	0.11	0.024
Rock Creek main interceptor	5	27.89	1.70	0.05	0.014
Northeast boundary trunk sewer	6	23.35	0.05	0.002	0.001
Easby Point trunk sewer	7	10.00	4.56	1.17	0.117
Tiber Creek trunk sewer	—	18.20	0.43*	0.43*	0.078*
Main sewage pumping station	—	108.59	0.12*	0.10*	0.109*
Total	—	109.4	—	0.31	0.343

* For 3½-yr period, July 1, 1951, to December 31, 1954.

TABLE X.—Summary of Overflows from All Combined-System Areas, 1956–8*

Item	Sanitary Sewage Overflowed to Streams	
	% of Avg Flow in Sewers	Yearly Avg Quantity (mgd)
Overflow resulting from rainstorms	3.02	3.31
Overflow during dry weather	0.31	0.34
Total, for 109.4 mgd	3.33	3.65

* From Tables VIII and IX.

combined-system areas. It was found that in the 3-yr period 2 per cent of this sanitary sewage was overflowed during rainstorms and 0.15 per cent during dry weather. These overflows from separate-system areas produced a total average overflow quantity of 0.68 mgd.

The percentage of time when overflow occurred as a result of rainstorms (Table VIII, Col. 5) was compared with the percentage of time for different rates of low precipitation. Data for the latter are given in Table XI.

Table VIII shows that the duration of wet-weather overflow varied from 4.00 to 5.15 per cent of the time, except at two points. Table XI indicates that these percentages are applicable to the occurrence of precipitation of about 0.03 in. or more. This indicates that little or no runoff occurred from precipitation of 0.02 in. or less, and that runoff started with about 0.03 in. of precipitation. Therefore, in estimating the stormwater runoff for these studies, it has been considered that the runoff is zero from isolated rainfalls of 0.01 to 0.02 in. and from the first 0.02 in. of any rainfall. It was observed on the gage records that such rainfall amounts usually resulted either in no runoff or in insignificant runoff.

TABLE XI.—Amount of Time for Precipitation of Different Rates, 1956–8

Precip. in 1.0 Hr (in.)	No. of Hours	% of Time
Trace or more	3,886	14.8
0.01	1,957	7.4
0.02	1,381	5.3
0.03	1,080	4.1
0.04	855	3.3
0.05	690	2.6
0.06	580	2.2
0.07 ↓	500	1.9

The overflow at the two points shown in Table VIII where the percentage of time is not consistent with the other values (Tiber Creek trunk sewer and main sewage pumping station), is controlled artificially by the operation of the pumping station. Therefore, the duration of overflow here has no definite relation to rainfall amounts, as it does for the other locations.

Future Overflows

An estimate was made of future overflows from combined-system areas occurring at points upstream of the sewage treatment plant, after completion of the program of improvements. This overflow, all resulting from rainstorms, would amount to an average of 0.38 mgd, equivalent to 0.42 per cent of the sewage flow from the areas which would still have combined sewers at that future date. This amount of overflow is considered not objectionable, at the locations and times when it will occur.

A detailed study is now being made of future overflows at the sewage treatment plant, due to rainstorms, with a view to providing limited treatment for such overflowing liquid. This overflow will result because the outfall sewers to the treatment plant will have a capacity equivalent to five times the yearly average dry-weather flow, while the treatment plant will have a capacity of only about twice the average flow.

Conclusion and Acknowledgments

The study provided city officials with engineering estimates of the actual overflows of sanitary sewage, both

present and future, which were of great help in developing and promoting the program of sewerage improvements.

For the District of Columbia, the work was under the direction of David V. Auld, Director of Sanitary Engineering; Roy L. Orndorff, Deputy Director of Sanitary Engineering; Emil A. Press, Superintendent, Office of Planning, Design and Engineering; and George J. Moorehead, Chief of Planning Branch, Office of Planning, Design and Engineering. The cooperation and assistance of these and other officials and staff members of the Department of Sanitary Engineering are gratefully acknowledged.

For Metcalf & Eddy, the work was under the direction of Frank A. Marston, Partner, with the author in immediate charge. G. S. Mustain, Civil Engineer, directed the computations and other detailed office work of the study.

HANEY RECEIVES VIRGINIA'S ENSLOW-HEDGEPETH AWARD

Cecil B. Haney (right), Superintendent of the Charlottesville treatment plant, is shown at the annual meeting of the Virginia Water Pollution Control Association receiving the Enslow-Hedgepeth award from Stuart C. Crawford, consulting engineer from Franklin. This is the second time this annual award has been given by the Virginia Association for an outstanding contribution to wastewater treatment and control.

SALARY SURVEY IN MUNICIPAL TREATMENT PLANTS IN INDIANA—1960

Indiana Water Pollution Control Association

In 1960 the Indiana Water Pollution Control Association made a survey of employee salaries in the operation of municipal wastewater treatment plants in Indiana.

The information has been assembled in tabular form and is being offered to readers of the Journal with the hope that it will stimulate similar surveys in other areas. It is hoped that these studies will lead to a general realization that communities have a real responsibility in providing salary scales which will attract the kind of employees who are willing and able to protect the waters of the area.

The data are tabulated or summarized by various types and sizes of treatment plants. Tabulations include: activated sludge over 25,000 population (Table I), trickling filter and primary over 25,000 (Table II), activated sludge serving 10,000 to 25,000 (Table III), trickling filter and primary for 10,000 to 25,000 (Table IV), all plants serving 5,000 to 10,000 (Table V), and all plants serving 2,500 to 5,000 (Table VI). Those plants serving less than 2,500 are summarized.

Sixteen plants reported in the class of those serving less than 2,500 population. Rather than presenting the

TABLE I.—Salaries of Personnel in Activated Sludge Plants Serving More Than 25,000 Population

Plant	Salary and Cost Allocation ($)									
	Supt.	Asst. Supt.	Chief Oper.	Oper.	Chemist	Maint.	Labor	Clerical	Monthly Cost	Monthly Cost P r Capita (¢)
1	575	500	425	425	—	425	255	350	8,000	16
2	450	—	385	345	255	365	—	285	8,240	22
3	650	550	380	370	380	365	305	350	9,500	26
4	810	570	—	460	650	460	355	320	14,400	11
5	710	500	380	370	390	380	290	300	15,000	35
6	1,000	830	440	425	500	600	410	365	15,000	9
7	825	630	475	470	595	525	350	315	16,000	10
8	850	675	550	405	520	610	330	335	—	—
9	900	620	550	480	360	470	405	409	20,000	15
Average	753	610	449	417	447	467	338	337	—	18
1956 avg	680	535	415	350	400	380	307	335	—	—

TABLE II.—Salaries of Personnel in Trickling Filter and Primary Plants Serving More Than 25,000 Population

Plant	Salary and Cost Allocation ($)									
	Supt.	Asst. Supt.	Chief Oper.	Oper.	Chemist	Maint.	Labor	Clerical	Monthly Cost	Monthly Cost Per Capita (¢)
1	—	550	—	413	300	460	325	—	4,500	11
2	500	—	—	305	—	—	240	240	6,500	21
3	—	500	—	330	330	330	250	—	6,700	16
4	685	—	365	330	325	320	300	270	7,400	15
5	650	455	370	350	350	370	285	275	13,000	9
Average	612	502	368	346	327	370	280	262	—	15
1956 avg	575	435	—	323	—	322	225	—	—	—

TABLE III.—Salaries of Personnel in Activated Sludge Plants Serving 10,000 to 25,000 Population

Plant	Salary and Cost Allocation ($)								
	Supt.	Asst. Supt.	Oper.	Chemist	Maint.	Labor	Clerical	Monthly Cost	Monthly Cost Per Capita (¢)
1	375	—	305	305	—	305	295	2,500	21
2	—	—	355	→	390	300	275	3,430	24
3	475	—	375	383	—	305	335	3,598	24
4	500	325	290	250	—	200	—	3,685	18
5	410	—	395	300	—	310	350	5,430	31
6	625	325	305	—	390	245	230	5,700	27
Average	477	325	338	310	390	278	297	—	25

TABLE IV.—Salaries of Personnel in Trickling Filter and Primary Plants Serving 10,000 to 25,000 Population

Plant	Salary and Cost Allocation ($)								
	Supt.	Asst. Supt.	Oper.	Chemist	Maint.	Labor	Clerical	Monthly Cost	Monthly Cost Per Capita (¢)
1	375	335	—	—	—	—	300	1,000	6
2	507	415	—	—	—	—	295	1,457	8
3	500	—	330	—	—	—	265	1,820	10
4	455	—	340	—	—	—	300	3,262	15
5	310	375	310	330	310	290	—	3,327	22
6	600	—	350	275	375	255	300	3,900	31
Average	458	375	333	303	343	273	292	—	16

TABLE V.—Salaries of Personnel in All Plants Serving 5,000 to 10,000 Population

Plant	Salary and Cost Allocation ($)					
	Supt.	Asst. Supt., Oper.	Labor	Clerical	Monthly Cost	Monthly Cost Per Capita (¢)
1	—	270	—	—	270	6
2	—	275	190	—	465	6
3	300	250	—	—	550	10
4	290	280	—	—	570	7
5	—	275	255	—	640	10
6	325	—	245	—	700	12
7	415	345	—	—	759	12
8	—	255	255	255	984	12
9	275	250	—	225	1,191	20
10	410	320	255	250	1,400	17
11	365	360	255	250	1,850	26
12	310	290	210	240	1,855	26
13	375	340	270	—	1,903	23
Average	341	293	242	244	—	15

TABLE VI.—Salaries of Personnel in All Plants Serving 2,500 to 5,000 Population

Plant	Salary and Cost Allocation ($)			
	Supt.	Other Help	Monthly Cost	Monthly Cost Per Capita (¢)
1	—	220	220	5
2	300	—	300	7
3	325	—	325	9
4	—	225	325	11
5	300	—	350	5
6	400	—	400	10
7	335	222	557	18
8	300	275	575	17
9	390	265	700	32
10	425	310	830	12
Average	347	253	—	13

data in tabular form, a summary follows: Eight of the plants were poorly operated and maintained. An average amount of $265 per month (range of $65 to $700) was charged to the sewage utility. Cost per capita ranged from 3¢ to 50¢ a month with an average of 12¢.

PHS GRADUATE TRAINING

The Public Health Service is accepting applications for graduate training in public health for the 1961–62 academic year. Sanitary engineers, public health educators, and laboratory personnel are included in the eligible areas of training.

The awards provide stipends for living expenses of the trainees in addition to tuition and fees. Information and application forms may be obtained from the Division of Community Health Practice, Public Health Service, Washington 25, D. C.

FROTHING OF DETERGENTS IN THE PRESENCE OF CARBOHYDRATES, PROTEINS, AND FATS

Gail P. Edwards, V. Kesavulu, Sheldon Smith, and K. B. Lulla

Published reports are in disagreement as to the effect of detergents on the activated sludge process and especially as to the causes of frothing. It has been very difficult to establish the truth of the many theories. For example, though many claim that frothing is caused by detergents, Gowdy (1) has stated that frothing may be due to compounds produced during the biological oxidation. In support of this theory, he pointed out that the frothing is greatest at the effluent end of the aeration tank.

Most of the coarse solids are removed from sewage in the primary settling tanks and the liquid entering the aeration tanks is colloidal in nature, containing various types of materials such as proteins, carbohydrates, oils and fats, and some inorganic solids. There is also a variety of soluble substances, both organic and inorganic. The colloidal nature of the solution is a major factor in frothing. As the colloidal particles pass through the aeration tanks, they are adsorbed on the activated sludge floc and acted on by microorganisms. They are partly oxidized and partly assimilated by the microorganisms with a resulting increase in sludge solids. Part of the organic and inorganic substances which are resistant to biological oxidation is discharged in the final effluent and part is removed by adsorption on the sludge.

Gail P. Edwards is Professor of Sanitary Chemistry in the College of Engineering at New York University, New York; V. Kesavulu is Research Fellow at the Institute of Molecular Physics, University of Maryland, College Park, Md.; Sheldon Smith is Assistant Public Health Engineer with the Nassau County Health Department, Garden City, N. Y.; and K. B. Lulla is Assistant Research Scientist in the College of Engineering at New York University.

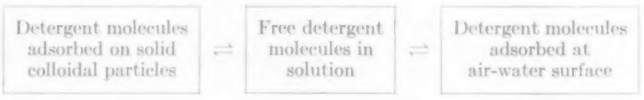
Chemical and Physical Characteristics

In determining the effect of detergent on the properties and behavior of these organic and inorganic colloidal particles as they pass through the various stages of biological oxidation, the first step would involve a careful study of the chemical and physical characteristics of detergents, proteins, starches, and other materials normally found in sewage and the reactions between them.

The molecules of all soaps and detergents possess a polar and a nonpolar end. The molecules in solution have a tendency to accumulate at the air-water interface. There they orient themselves in such a way that the polar groups are in the water and the nonpolar ends extend out into the air.

Since sewage contains a large number of colloidal particles, many of the detergent molecules in solution are adsorbed on them. Many protein molecules are capable of forming stoichiometric complexes with detergent molecules. For example, Putnam and Neurath (2) have identified two types of complexes formed between horse serum albumin and dodecyl sulfate.

Edwards and Ginn (3) pointed out that much of the detergent is rapidly adsorbed by the sludge during an aeration cycle in an activated sludge plant. All colloidal particles, to a greater or lesser extent, are capable of adsorbing the detergent molecules. Most of the detergent initially present in the sewage is either adsorbed on the colloidal particles or at the air-water interface. Few free molecules are in solution and it can be assumed that, at first, the following equilibrium exists in sewage as it enters the aeration tank:


Detergent molecules adsorbed on solid colloidal particles
Free detergent molecules in solution
Detergent molecules adsorbed at air-water surface

The direction in which the equilibrium is shifted is determined by the free energies involved. If the adsorption on colloidal particles is mainly chemisorption, as is the case in the protein-detergent interaction, the equilibrium will be shifted toward the left. Chemisorption involves greater free energy changes than does physi-sorption.

These considerations apply to static conditions. But in an aeration tank, a steady stream of air bubbles passes through the liquid medium and the equilibrium is continually disturbed. Furthermore, the microorganisms act on the organic colloidal particles as well as on the adsorbed molecules. Proteins, starches, and other natural organic materials are changed by the organisms. Sawyer and Ryckman (4) have shown that some detergents and soaps are destroyed during the biological oxidation process but the alkyl benzene sulfonates which form a major portion of the commercial product are extremely resistant to biological attack. With the removal of the colloidal substrate, the detergent molecules will gradually be set free and accumulate in the solution, eventually becoming a cause of frothing. The fact that frothing in aeration tanks occurs in the later stages of treatment rather than in the initial stages seems to support this hypothesis. It is true that part of the liberated detergent would be readsorbed by the newly formed sludge but the surface presented for adsorption by this sludge would be only a small fraction of the colloidal particles.

An additional frothing agent may be produced during the biological oxidation. If this is the case, the frothing agent would likely be one of the degradation products of proteins, starches, and organic materials which may normally be expected in sewage.

Test Procedure

It is desirable, therefore, to make a preliminary study of the effects of starches, proteins, and fats and some of their degradation products on the frothing characteristics of pure detergent solutions. Starches would be expected to be degraded to maltose and glucose. Proteins would furnish polypeptides and amino acids. Oils and fats would yield fatty acids and glycerol. Compounds simpler than these would probably not be important.

To determine and compare the effects of different organic materials and their degradation products on the frothing characteristics of detergent solutions, standard procedures and conditions must be established. Throughout this work, the anionic detergent Naccconol, NRSF, an alkyl benzene sulfonate, was used. Various methods of measuring frothing were tried and discarded. In the protein studies, a tube, two inches in diameter, with a fused alumina diffusion stone was used. The main difficulty in measuring froth height is that although initially a dense froth is produced, it gradually thins out and

breaks into sections even at low air rates. It is almost impossible to judge when the thick froth begins to thin out. A thick foam only 10 in. high may reach 20 in. or more as it thins out before breaking into sections. Different air rates had little effect. The values for foam height are therefore estimates for showing relative heights rather than accurate figures.

A tube, 2.75 in. in diameter, seemed best for the frothing experiments and was used in the rest of the studies. Even with this tube, thinning and breaking trouble occurred if the froth height went beyond six or seven inches. The volume of the solution and the concentration of detergent had to be controlled to keep the foam within proper limits. Compressed air from a cylinder was diffused through a sintered disk of medium porosity to cause frothing and a calibrated flow meter in the system permitted control of the air rate.

Results and Discussion

Preliminary experiments on the frothing characteristics of detergent solutions indicated that the maximum foam height rose with increase in detergent concentration (Figure 1) but the time required for maximum height also increased with the concentration. It was also observed that the greater the air rate, the greater the maximum froth height.

The effect of pH on detergent foaming is shown in Figure 2. As the pH rose, the foam height increased from 0.25 in. at pH 2.5 to 1.6 in. at pH 7, and it remained at that level to about pH 11. There was a sharp increase in foam height as the pH rose from 4 to 6.

Carbohydrates

The effect of starch, maltose, and glucose on the frothing characteristics of an anionic detergent are shown in Figure 3. Each batch of potato starch solution had a different effect on the foaming of detergent solutions, but qualitatively, the same inhibiting trend was noted in all cases. As the starch concentration increased, the foaming ability of the detergent solution decreased (Figure 3). Starch from one batch stopped frothing completely with

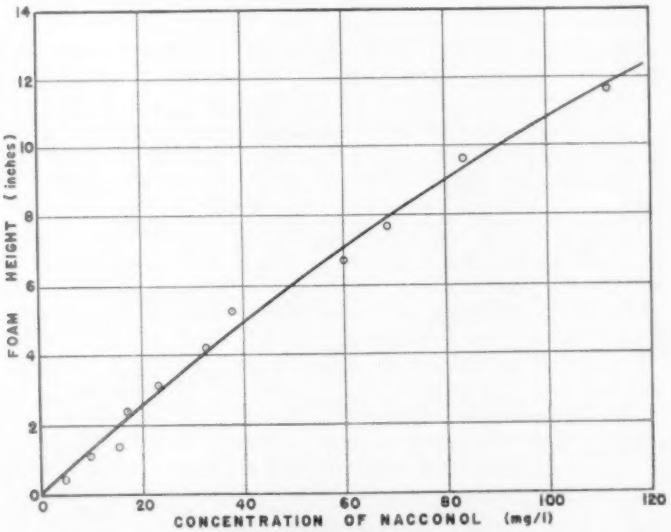


FIGURE 1.—The effect of detergent concentration on foam height.

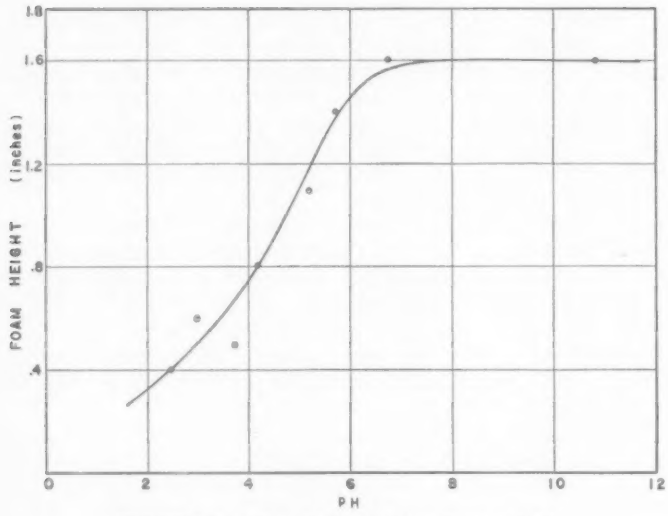


FIGURE 2.—The effect of pH on foam height.

starch concentrations as low as 100 mg/l, whereas solutions from other batches required more. Different particle sizes in the various starch solutions may have affected the result.

Of the three carbohydrates studied, starch was most effective in preventing froth formation in solutions of Nacconol. Maltose reduced the frothing somewhat and glucose was only slightly effective. In the case of starch, the inhibiting effect may be attributed to adsorption of detergent on starch particles.

Proteins

It was indicated by Moss (5) that proteins and protein degradation prod-

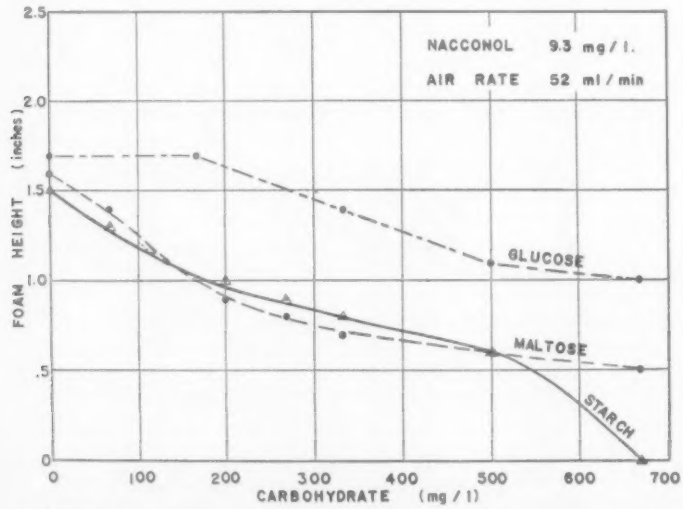


FIGURE 3.—The effect of carbohydrates on the foaming of Nacconol.

ucts may play an important part in accentuating or stabilizing froth in sewage. It is also well known that synthetic detergents will react with protein because of the electrostatic charges carried by the protein and detergent and because of the attraction of the organic segment of the detergent for the protein. These phenomena have been explained in two different ways. One explanation is that the interaction is a purely physical surface adsorption. On the other hand, Putnam and Neurath (2), Brill (6), and Aoki and Hori (7) have reported stoichiometric complex formations between proteins and detergents. Gortner and Gortner (8) and Valko (9) take an intermediate stand and recognize the interplay of both chemical combination and physical adsorption. According to Gortner and Gortner (8), acid base reactions with protein systems are not completely accounted for stoichiometrically and there is evidence that adsorption accounts for at least a part of the apparent acid and base bindings in protein systems. For example, casein, in contrast to succinic acid, does not possess a "maximum base binding capacity" but, in addition to the stoichiometric binding of the base by the acid casein, there is a second reaction which apparently yields an adsorption isotherm.

Some proteins in aqueous solution, on standing, will form insoluble films on the surface of the solution. Disrupting and breaking the surface causes these films to roll up and form coagulated clumps. By breaking old surfaces and exposing new ones either mechanically or through aeration, the protein can be entirely transferred from the solution to the froth. This surface denaturation phenomenon for a dilute egg albumin solution has been explained as a positive adsorption of protein at the gas-liquid interface where surface energy coagulates the albumin in much the same way as coagulation by heat.

When casein solutions of high concentration, adjusted to pH 7, were aerated, a thick foam was produced. At low concentrations (10 to 50 mg/l) only large stable bubbles and film pockets were formed and the phenomenon of surface coagulation was easily observed. The rising air bubbles formed pockets of air above the solution surface by lifting the protein surface films. The very low surface tension of the protein films was indicated by the slowness with which they broke. These films broke by slowly rolling back and the coagulated casein then formed clumps which eventually became an insoluble ring of protein on the inside of the aeration tube. Studies made to determine the effect of pH indicated a tendency toward less bubble and film pocket formation as the pH of the casein solution decreased to the isoelectric point (pH 4 to 4.5). At that point, the casein, if not already precipitated, seems to be in an unstable state in which it will not form films.

Interactions between proteins and detergents have been studied by various investigators. Since the charge carried by the protein molecule depends on the pH of the solution, there may be expected to be different reactions between a given protein and an anionic detergent and the same protein and a cationic detergent. For example, the addition of Nacconol to a casein solution at a pH value below the isoelectric point causes precipitation, whereas cetyl trimethyl ammonium bromide, a cationic detergent, causes precipitation of casein above the isoelectric point. Aoki and Hori (7) have studied these effects with egg albumin and various detergents. In the region where precipitation does not take place, e.g., where the pH is above the isoelectric point in a solution of an anionic detergent and protein, or below the isoelectric point with a cationic detergent, they found that the mode of interaction for many proteins is that of a discrete stoichiometric complex formation. Because of this interaction

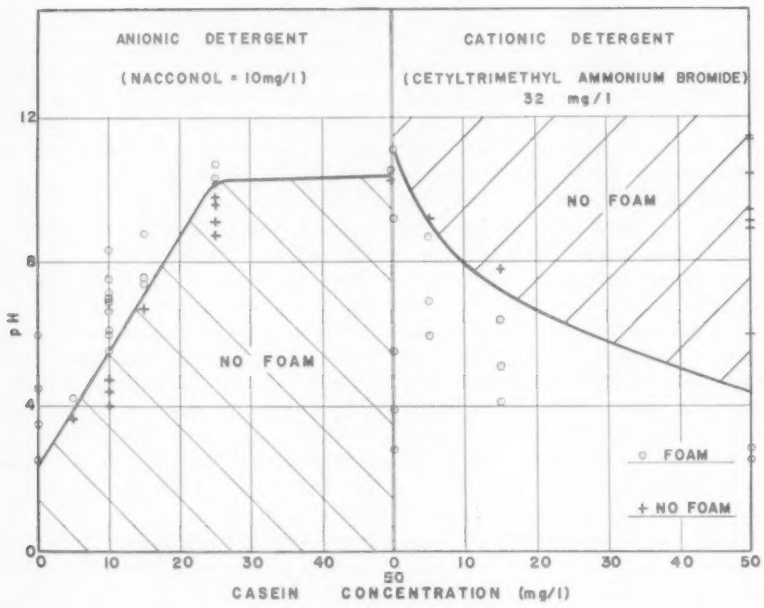


FIGURE 4.—Effect of casein concentration and pH on foaming of an anionic detergent and a cationic detergent.

of proteins with detergents, proteins in conjunction with pH, can be expected to have a profound effect on the foaming characteristics of detergent solutions.

Experiments were conducted in which casein was aerated with detergents. It was found that at certain pH values, the casein would prevent frothing. The results of these experiments suggested that under certain conditions of pH, the casein combined with enough free detergent to prevent frothing.

The effect of casein on the foaming characteristics of an anionic detergent (Nacconol) and a cationic detergent (cetyl trimethyl ammonium bromide) was determined over a wide pH range. In order to maintain a suitable foam height, the concentration of Nacconol was held at 10 mg/l; the CTAB (cetyl trimethyl ammonium bromide) at 32 mg/l; and the air rate at 52 ml per minute. The results shown in Figure 4 indicate the range of pH values and casein concentrations over which the the transition from foam to no foam occurs.

By a titration technique, the relationship between the concentration of Nacconol required for foam production as a function of casein concentration at pH 7 was determined. Figure 5 shows that, as the concentration of casein is increased, more and more Nacconol must be added in order to form froth.

To determine the effect of protein on the frothing of Nacconol at pH 7, casein and egg albumin were used. Two concentrations of detergent were aerated with various amounts of casein and in each case, as the concentration of casein increased, the amount of froth, measured by the height, decreased. It is shown in Figure 6 that 17.5 mg/l of casein prevented frothing in a solution containing 10 mg/l of detergent and 50 mg/l of casein prevented frothing in a 20-mg/l solution of detergent. Figure 7 shows that the egg albumin also had an inhibiting effect on froth formation but less than casein.

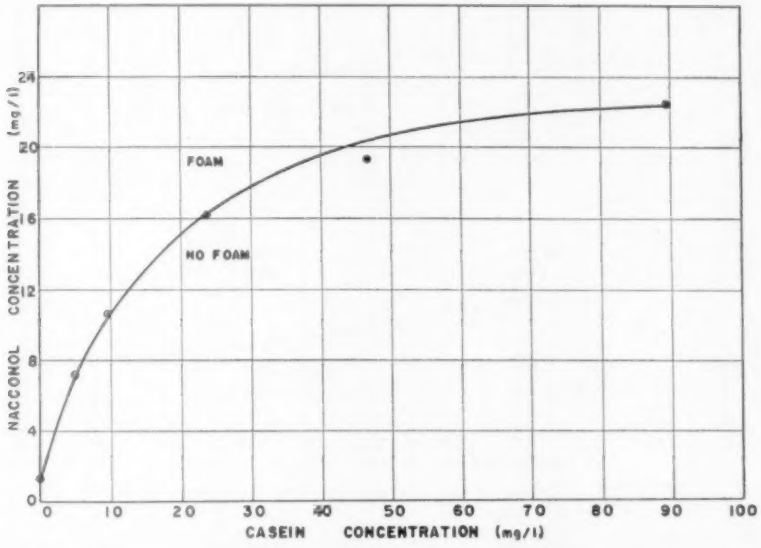


FIGURE 5.—Concentration of Nacconol required for foam production as a function of casein concentration at pH 7.

The effect of two degradation products of proteins, casamino acids, and proteose peptone, on the frothing of Nacconol was also examined. Pure casamino acid solutions at pH 7, ranging in concentration from 25 to 500 mg/l, did not foam on aeration and had practically no effect on the froth height of an aerated detergent solution containing 10 mg/l Nacconol (Fig-

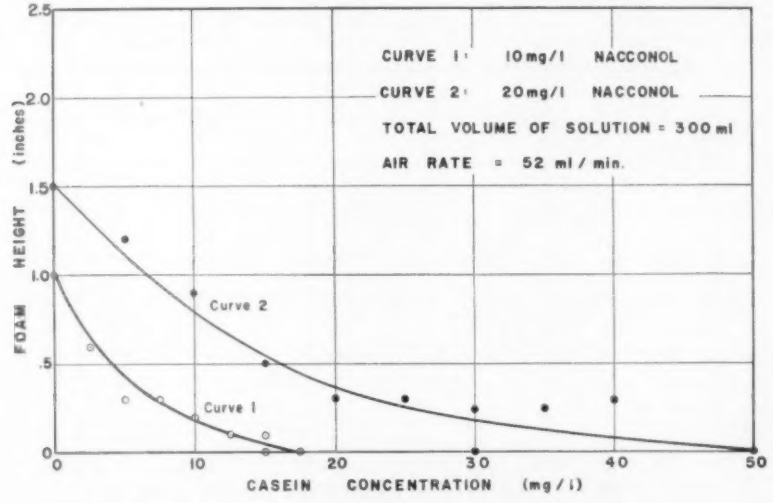

CURVE 1: 10 mg/l NACCONOL
CURVE 2: 20 mg/l NACCONOL
TOTAL VOLUME OF SOLUTION = 300 ml
AIR RATE = 52 ml / min.
FOAM HEIGHT (inches)
Curve 2
Curve 1
CASEIN CONCENTRATION (mg/l)

FIGURE 6.—The effect of casein concentration on the foaming of Nacconol at pH 7.

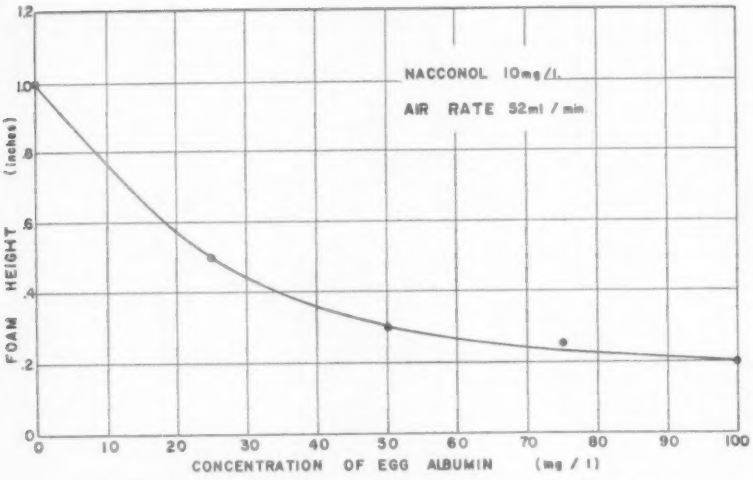


FIGURE 7.—Effect of egg albumin on foam production at pH 7.

ure 8). Proteose peptone, on the other hand, frothed slightly on aeration in concentrations greater than 100 mg/l (Figure 9) and in low concentrations (10 to 25 mg/l) proteose peptone seemed to have a significant inhibitory effect on the frothing of Nacconol. At concentrations of proteose peptone greater than 50 mg/l, mixtures with Nacconol produced more foam on aeration than the Nacconol itself did.

Mixtures of casein and casamino acids or proteose peptone were aerated with Nacconol. The total concentration of the protein and degradation products in these mixtures was kept constant and as the proportion of casein to degradation products decreased, the froth-inhibiting power of the mixture decreased.

Vegetable Oils

Peanut oil was used as an indication of the effect of vegetable oils on froth-

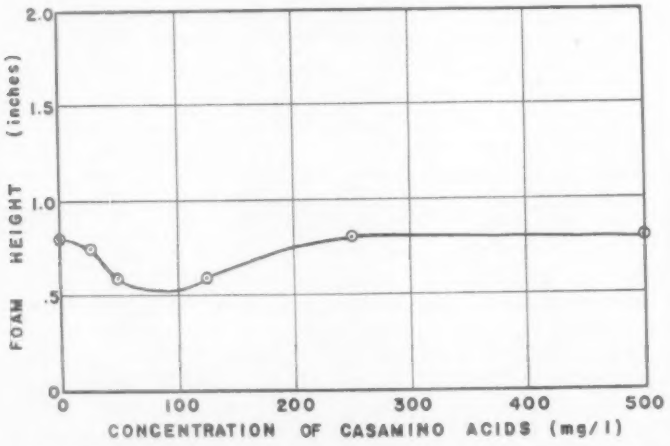


FIGURE 8.—The effect of casamino acids on the foam height of a detergent solution. (10 mg/l Nacconol, pH 7.)

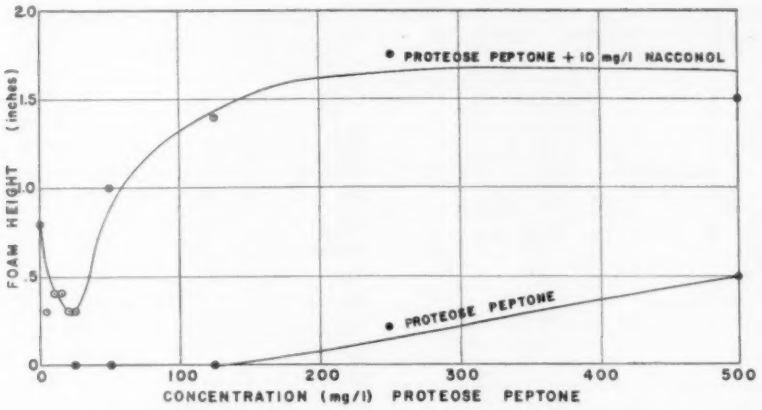


FIGURE 9.—The effect of proteose peptone on the foaming of a detergent solution.

ing. A stock emulsion of peanut oil in water (1,500 mg/l) was made in a high-speed mixer. The aeration of oil-water emulsions of various concentrations produced no froth. When oil emulsions were aerated with Nacconol, foam formation was greatly inhibited. As shown in Figure 10, 10 mg/l of oil reduced froth formation 60 per cent, as measured by froth height, when aerated with a 10 mg/l Nacconol solution at pH 7. About 100 mg/l of peanut oil were required to prevent frothing in the 10-mg/l detergent solution. In a 20-mg/l Nacconol solution, more peanut oil was required to reduce the frothing to the same degree but the general effects were the same.

Removal of Detergent from Solution

The removal of detergent from the solution by transfer to the foam depends on the amount of foam produced and, therefore, on the concentration of detergent, the air rate, and the aeration period. For example, Table I shows that the removal of detergent from a solution initially containing 24.6 mg/l Nacconol, increased from about 5 per cent at 28 ml of air per minute to

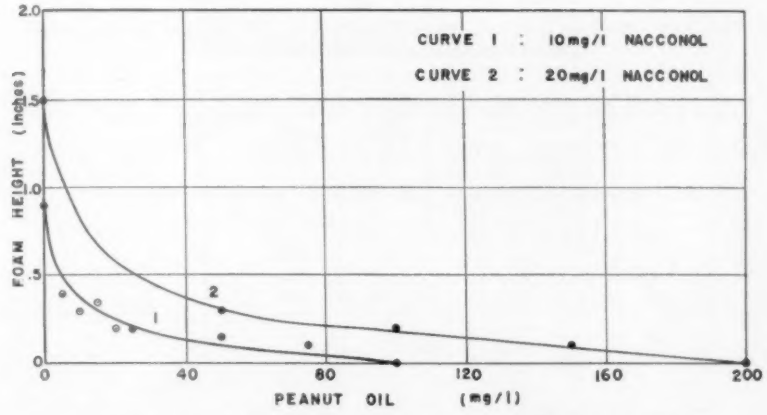


FIGURE 10.—Foam height vs. peanut oil concentration at pH 7.

TABLE I.—Removal of Detergent from Solution by Aeration (Initial Concentration of Nacconol, 24.6 mg/l)

Air Rate (ml/min)	Detergent		
	Concentration of Original Solution (mg/l)	Concentration After Foaming (mg/l)	Per Cent Removal
28	24.6	23.3	5.3
50		20.5	16.7
65		21.8	11.4
85		20.5	16.7
101		19.8	19.5
126		19.5	20.7
154		17.3	29.7

nearly 12 per cent at 60 and to about 30 per cent at 154 ml/min during 12 min aeration. That the length of the aeration period is important is indicated by the data which showed that, at an air rate of 60 ml/min, the removal of detergent from a solution containing 25 mg/l Nacconol increased from about 10 per cent in 5 min to about 33 per cent in 35 min.

These data indicate that the removal of detergent in the froth is an equilibrium phenomenon and that the detergent distributes itself between froth and liquid. The distribution depends on such conditions as the air rate and the rate of evaporation of the water in the foam. Except for the evaporation from the surface of the foam and the consequent drying, the usual distribution law may be expected to determine the distribution between liquid and foam.

The removal of detergent from solutions containing starch and starch with maltose followed the same trend as in the pure detergent solutions. Table II shows that as the foam height was reduced by the activity of the carbohydrate, the removal of detergent decreased. The determination of the amount of detergent was made by the Edwards-Ginn (3) (10) modification of the two-phase titration method since starch had practically no effect on this method. The methylene green colorimetric method did not give reproducible results in the presence of starch.

Summary

Neither starch, maltose, nor glucose produced froth on aeration but they do tend to inhibit frothing in Nacconol solutions. Proteins such as casein and egg albumin did produce froth on aeration. Low concentrations of casein were effective in preventing frothing of Nacconol solutions. Egg albumin was less effective than casein. Degradation products such as casamino acids had no effect on the frothing of Nacconol but low concentrations of proteose peptone reduced foam height. Emulsions of peanut oil in water in con-

TABLE II.—Removal of Detergents by Foaming in the Presence of Carbohydrates (Initial Concentration of Nacconol, 9.3 mg/l)

Conc. Starch (mg/l)	Foam Height (in.)	Detergent		Conc. Starch (mg/l)	Conc. Maltose (mg/l)	Foam Height (in.)	Detergent	
		Remaining in Solution (mg/l)	Removal (per cent)				Remaining in Solution (mg/l)	Removal (per cent)
0	1.5	7.8	16	0	0	1.5	6.9	26
67	1.3	7.9	15	0	667	0.9	6.9	26
133	1.1	—	—	67	600	0.9	—	—
200	1.1	7.7	17	133	534	0.7	6.7	28
267	0.9	8.0	14	200	467	0.7	6.8	27
333	0.8	8.1	13	267	400	0.7	6.9	26
500	0.6*	9.3	0	333	333	0.6	7.5	19
667	0	9.3	0	500	167	0.6	7.5	19
				667	0	no foam	9.1	2

* Foam disappeared after four minutes of aeration.

centrations of about 100 mg/l were effective in preventing foam formation.

No evidence was found to show that the common food types, carbohydrates or fats, produced foam when aerated. Proteins foamed on aeration and a degradation product, proteose peptone, formed a slight amount of froth. Casamino acids on the other hand, showed no frothing tendency.

All of these substances except casamino acids tended to reduce the frothing properties of Naccconol. Casamino acids had no effect.

Acknowledgment

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34th ANNUAL MEETING

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DESIGN OF SLUDGE REAERATION ACTIVATED SLUDGE SYSTEMS

Roy F. Weston

Several sludge reaeration processes have been used. Among the names applied to this principle are "bioflocculation," Biosorption,* "contact stabilization," and "sludge reaeration." Each process has the identical flow diagram shown in Figure 1.

Bioflocculation was developed in England in 1921. The first plant was placed in operation in 1930 (1). This plant provided 30-min mixed liquor aeration time and 8-hr return sludge reaeration.

In the late 1940's Eckenfelder and Hood (2) carried out research on this type of process at Ridgewood, N. J. At about the same time, Ullrich and Smith (3) started other investigations in Austin, Tex. The process developed from these studies became known as Biosorption. Biosorption used an arbitrary 35-min mixed liquor aeration time and a 2½-hr return sludge stabilization time.

Others have used sludge reaeration in conjunction with the conventional activated sludge process. There has been no well-defined design basis for this process modification.

Important prerequisites of sound design are (*a*) development of a fundamental theory of behavior, and (*b*) establishment of realistic design parameters.

Weston and Eckenfelder in 1955 (4), postulated that:

1. On admixture of a well-acclimated and stabilized activated sludge with an organic waste an enzyme complexing reaction takes place which immediately removes organic matter from solution and associates the organic matter-enzyme complex with the sludge. The quantity of complex formed is a function of the waste concentration, the activated sludge concentration, and the enzyme content of the sludge. The quantity of complex formed may be predicted using physical-chemical principles and reaction coefficients applicable to the specific system. The complex is removed from the mixed liquor along with the sludge.

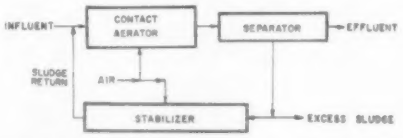

FIGURE 1.—Schematic diagram of sludge reaeration process in activated sludge treatment.

2. Following initial removal, organic matter (that is, BOD) is further removed in accordance with the logarithmic growth law of bacterial multiplication. A portion of the BOD removed is synthesized to protoplasm and the remainder is oxidized to provide energy for synthesis.

3. Log growth phase removal of BOD occurs until some equilibrium BOD concentration remains. The equilibrium concentration remaining is generally a constant percentage of the initial BOD concentration. The con-

* Biosorption is a registered trademark of Infilco Inc.

Roy F. Weston is President of Roy F. Weston, Inc., Newtown Square, Pa.

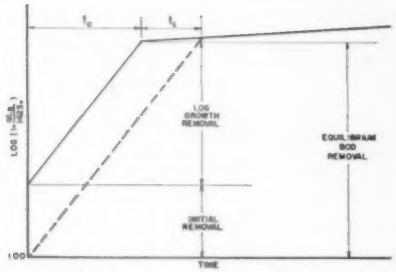

FIGURE 2.—Typical growth ratio plot.

centration is predictable for any given system.

BOD Removal

If these postulations are correct, it should be possible to establish growth ratio plots from batch treatment data. This was found to be true. A typical plot in shown in Figure 2. From such plots, for different BOD-activated sludge suspended solids ratios, it is possible to establish correlations for initial BOD removal, log growth phase removal, and equilibrium BOD remaining. Typical correlations are shown in Figures 3, 4, and 5.

Significant quantities of BOD are removed from domestic sewage on immediate contact with stabilized activated sludge. The high initial removal applies to both unfiltered and filtered samples. In the case of the observations shown in Figure 3, the median initial removal was about 76 and 68 per cent, respectively, for unfiltered and filtered sewage ($S_0 = 7{,}770$ mg/l). In this as well as other cases, substantial initial removal is obtained with soluble as well as colloidal BOD.

This evidence makes it apparent that there is now a quantitative procedure for estimating BOD removal rates and equilibria.

More recent theories by Weston and Stack (5) and rate constant developments by Stack (5) have simplified BOD removal vs. time relationships, the calculation of BOD removal rate constants, and the estimation of continuous treatment plant efficiencies.

A typical plot of BOD remaining vs. time of mixed liquor aeration for batch treatment of sewage is shown in Figure 6.

Initial BOD removal, BOD removal rate constants, and equilibrium BOD remaining correlations determined from such simplified plots appear to be as reliable as correlations developed from the growth ratio plots (Figure 2). In

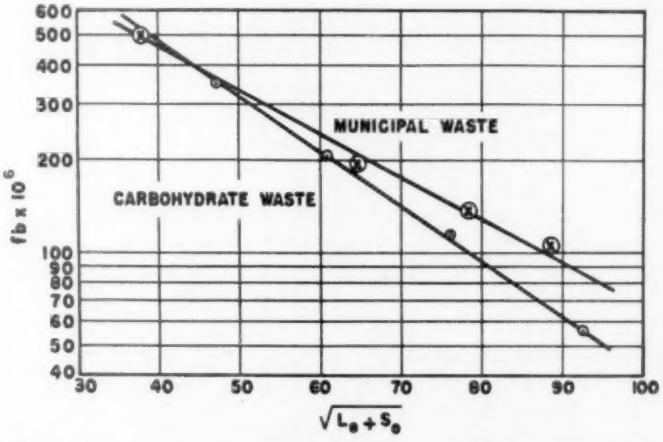

FIGURE 3.—Relation between initial BOD removal and concentration of reactants.

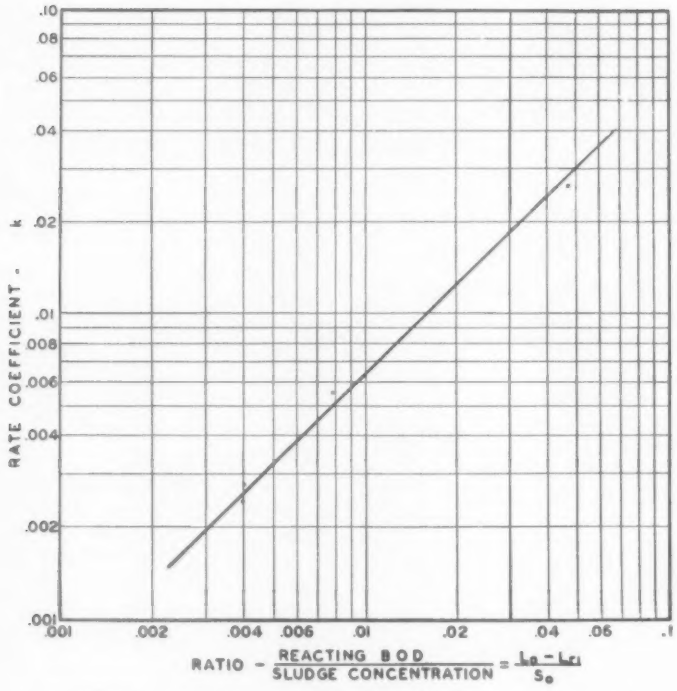

FIGURE 4.—Relation between rate of BOD removal and ratio of reactants.

fact, the correlations for initial BOD removal and equilibrium BOD remaining are identical.

A correlation of the removal rate constant r with BOD concentration remaining after initial removal is shown in Figure 7.

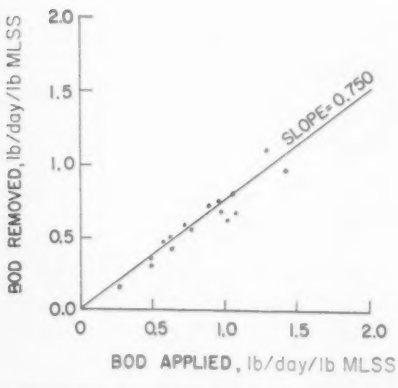

FIGURE 5.—BOD removal at equilibrium; laboratory batch tests on paper mill wastes.

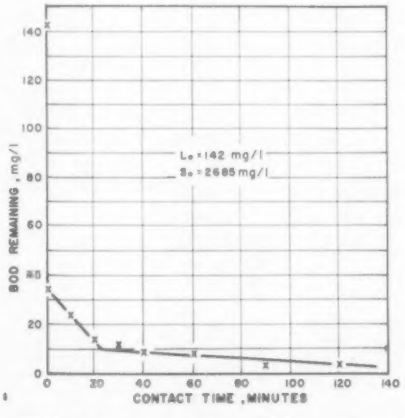

FIGURE 6.—Typical BOD removal from sewage in a batch activated sludge system.

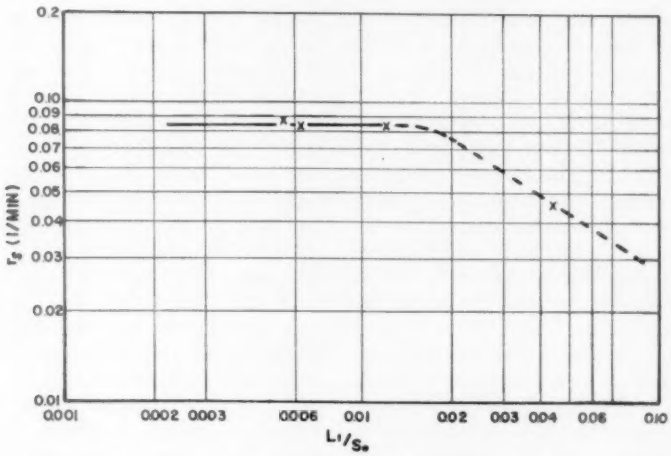

FIGURE 7.—Correlation of stabilization reaction rate constant for activated sludge treatment of sewage

Using either the original or more recent theories, it is possible to synthesize BOD removal plots and to estimate BOD removal efficiencies for predetermined or known treatment conditions.

Mixing Theory

The only obstacle to making efficiency predictions is that of converting batch data to continuous data. This involves the use of mixing theory, which was applied to a dispersed growth stabilization basin system (6).

Knowledge of the size of the mixed liquor aerating tank and the flowing through rate makes it possible to estimate the average aeration or retention time. Although the average time of aeration of the mixed liquor droplets is equal to the retention time, the aeration time for individual droplets varies from a fraction of the average to several times the average. The relationship between that fraction of the mixed liquor retained for a specific time t or longer and the relative retention time is shown in Figure 8 (7). This shows that 37 per cent of the mixed liquor has remained in a single tank the design retention time or longer.

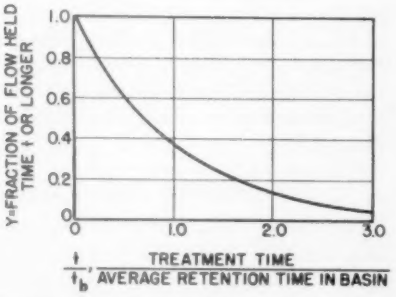

FIGURE 8.—Holding time in a completely mixed tank.

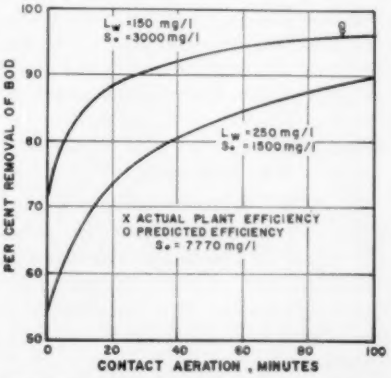

FIGURE 9.—Predicted results for contact stabilization treatment of sewage.

Since BOD removal is a time-rate reaction, if the reaction rate r and the retention time of a specific fraction of the mixed liquor are known, the per cent removal of the BOD can be estimated for different aeration times (5).

Allowing for initial removal, the BOD removal curve for a domestic sewage is as shown in Figure 9 for the given design conditions. This figure shows the agreement between a full-scale 8-hr plant run and the prediction from batch data.

The actual performance of the sewage treatment plant agreed with the theoretical efficiency curve. Good agreement between practice and theory has been demonstrated in numerous other cases.

The shape of this curve shows why a well-designed and well-operated activated sludge sewage treatment plant can maintain a nearly constant percentage BOD removal for widely variable operating conditions. This is due to the high initial removal characteristics of well-stabilized sludge.

Figure 9 shows that batch treatment data and mixing theory make it possible to determine the mixed liquor aeration time for any desired degree of treatment.

The contact aeration time design accounts for initial removal (if any) and the time required for log growth removal to the desired efficiency. The stabilizer design time accounts for the time required to metabolize waste matter associated with the activated sludge which remains after contact aeration.

Stabilization Time and Treatment Efficiency

The mixed liquor aeration time for a given degree of treatment is greatly dependent on the initial removal characteristics of the return sludge. Therefore, it is necessary to establish a rational basis for estimating the optimum stabilization time.

It has been estimated that the rate of oxidation of enzyme complexed organic matter would be the same as that in the system. Theoretically, the rate of stabilization should be the same as the rate of BOD removal during the log growth phase. Therefore, the BOD removal rate constant correlation of Figure 7 applies.

In the case of the sewage treatment example shown herein, the stabilization time for 90- and 95-per cent completion is 2 and 4 hr, respectively.

Weston and Stack (5) and Weston (8) confirm the fact that stabilization times for 90- to 95-per cent completion of reaction provide a reasonable estimate of the required minimum stabilization time. However, there appears to be little disadvantage for stabilization times moderately in excess of the minimum requirements. The minimum should be the stabilization time indicated for 90 per cent stabilization at design conditions.

The practical significance of stabilization is manifested in higher treatment efficiencies for given mixed liquor aeration times, greater stability of operation, and a reservoir of sludge in case of toxic conditions or other highly abnormal process conditions. Data showing the effect of stabilization are shown in Figure 10.

The total aeration time required for good contact stabilization operation on domestic sewage is substantially the same as that required of the conventional activated sludge process. Enzymes produced during the stabilization of mixed liquor in the conventional process may be sufficiently water soluble to be lost in the plant effluent. Enzymes produced in stabilizing return sludge are reacted with the waste. Therefore, higher initial removals are conceivable.

Flexibility of System

The tank volume required to stabilize mixed liquor is substantially greater than the volume required to stabilize return sludge. In case of 4-hr stabilization and 25-per cent recycle, 5

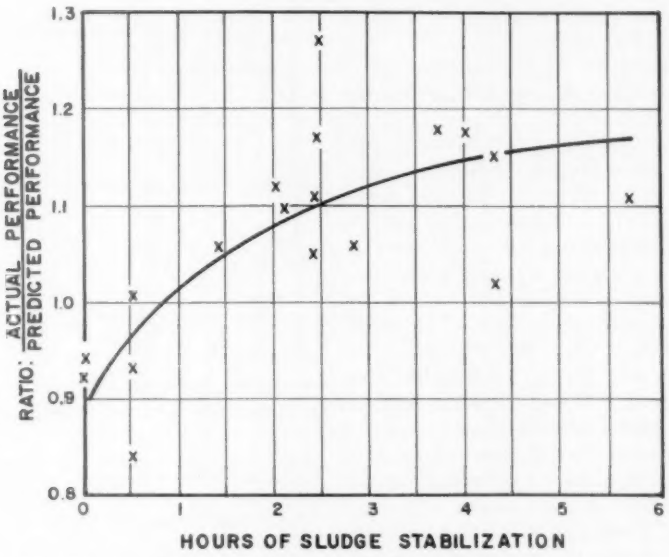

FIGURE 10.—Effect of sludge stabilization on process performance; paper mill waste.

times as much volume is required to stabilize mixed liquor as return sludge. Therefore, economies are possible.

The primary sedimentation of domestic sewage is not essential to the success of the process since primary sedimentation is not essential to any domestic sewage activated sludge process.

Experience has demonstrated that sludge reaeration processes such as contact stabilization are rugged in that they can stand wide variations in wastewater quality. The large supply of sludge in the stabilizer gives the process excellent recuperative capacity in case of toxic discharges.

There are many advantages to such processes as contact stabilization. Nevertheless, it is not the answer to all problems. It is most advantageous economically where initial removal is a significant factor. If the waste is not susceptible to initial removal, or if the BOD of the waste is sufficiently high that initial removal is relatively small, there is little economic advantage to the process. On the basis of operation considerations, it is most advantageous where a rugged process of excellent recuperative capacity is required.

This principle offers the most rugged and flexible activated sludge process known for wastes of low and medium strength (100 to 1,000 mg/l). The process can be designed for any desired degree of treatment using batch treatment data.

Oxygen Requirements

Theoretically, the oxygen requirements should be the same as those for conventional activated sludge with a mixed liquor aeration time equal to the contact plus stabilization times. The process with the larger aeration time, or times, will require the greater amount of oxygen because a greater portion of the sludge is oxidized. Consequently, less excess sludge is produced.

Oxygen is used for two basis purposes:

1. Biochemical oxidation of organic matter to synthesize protoplasm (acti-

vated sludge) and to supply the energy required for synthesis.

2. Oxidation of protoplasm (activated sludge); that is, autogenous respiration.

The oxygen requirements can be estimated from batch treatment data. Typical batch treatment data are shown in Figure 11. Theoretically and experimentally it can be shown that the rate of oxygen use is nearly a constant, for several hours, at the end of the sludge stabilization phase. As shown in Figure 2, the sludge stabilization phase follows the log growth BOD removal phase. Therefore, a line tangent to the accumulated oxygen use curve at the end of the sludge stabilization phase gives a good approximation for the rate of sludge oxidation. The oxygen use indicated by the zero time intercept of the tangent to the oxygen curve divided by the BOD removal at equilibrium gives the magnitude of the unit oxygen requirements for synthesis.

In the case of sewage, this is about 0.6 lb oxygen per pound BOD removed (that is, 5-day 20°C BOD).

The oxygen required for sludge oxidation depends on the age of the sludge; the older the sludge, the greater the oxidation. The relationship between total oxygen use and sludge age for a paper mill waste is shown in Figure 12. The effect of volatile suspended solids on the oxygen utilization rate can be determined from aerobic digestion experiments.

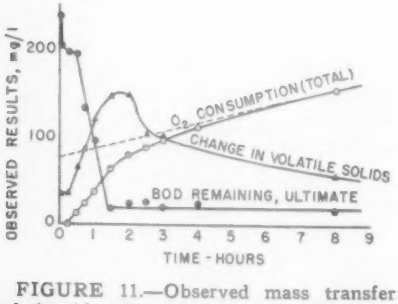

FIGURE 11.—Observed mass transfer relationships in a batch activated sludge system (food material, sucrose).

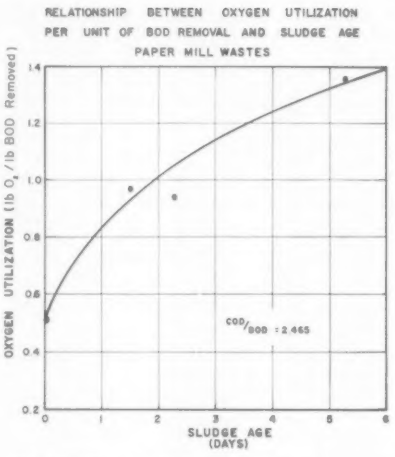

FIGURE 12.—Relation between oxygen utilization per unit of BOD removal and sludge age; paper mill waste.

The oxygen utilization rate for contact aeration is controlled by the rate of BOD removed. Oxygen transfer capacity must be provided for maximum BOD removal rates plus concurrent related sludge oxidation rates.

The oxygen utilization rate for stabilization is controlled by the rate of sludge auto-oxidation. Oxygen transfer capacity must be provided for maximum rates of sludge oxidation.

The actual oxygen transfer capacity to be provided is dependent on the maximum oxygen utilization rate and the coefficient of oxygen transfer, K_La. Detergents, other materials, and sludge concentration have a significant effect on the oxygen transfer coefficient. In some cases, wastewater oxygen transfer is only 50 per cent that of pure water. Obviously, this is highly significant in estimating blower capacities and turbine power.

The effect of such materials on oxygen transfer is different for compressed air than it is for turbines. Therefore, this fact must be taken into consideration in evaluating aeration economics.

Ordinarily, the minimum dissolved oxygen concentration allowable before interference with oxidation rates is 0.5

to 1.0 mg/l. However, in some systems threshold DO concentrations have been as high as 2.0 mg/l. This must be considered in aeration design.

Sludge Production

The amount of excess sludge production also can be estimated from batch treatment data. Typical batch treatment data are shown in Figure 11.

Excess sludge production can be estimated in the following manner:

1. An approximation of oxygen consumed by auto-oxidation is made by assuming that the rate of oxygen consumption after completion of sludge stabilization is due entirely to auto-oxidation.

2. Oxygen consumed to support synthesis reactions is assumed to be the net oxygen consumption after subtracting the amount consumed by auto-oxidation.

3. The net oxygen consumption is related to the observed removal of ultimate BOD as pounds of net oxygen consumption per pound of BOD removed.

4. The amount of synthesis is calculated by assuming that BOD removals which did not appear as oxygen consumption must appear as synthesized materials; that is,

$$\frac{1 - \dfrac{\text{lb oxygen}}{\text{lb BOD removed}}}{1.42} = \frac{\text{lb synthesized material}}{\text{lb BOD removed}} \quad \ldots (1)$$

This establishes the total amount of synthesis. To arrive at the excess production of sludge, the amount of sludge destroyed by auto-oxidation must be estimated. Typical curves (Figure 13) are obtained by following for several days the auto-oxidation of activated sludge used in the batch test. From these data, pounds of oxygen consumed per hour per 100 lb of sludge under

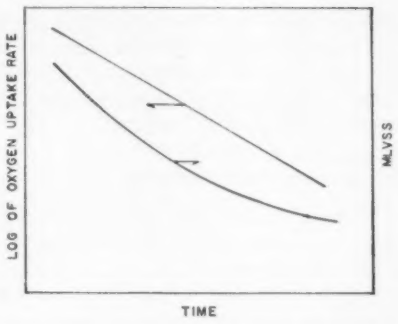

FIGURE 13.—Typical auto-oxidation data from batch systems.

aeration can be calculated for any particular volatile solids sludge concentration. When this quantity is divided by 1.42, the result is approximately the hourly rate of sludge destruction.

Net production of excess activated sludge produced by continuously-fed system is estimated as follows:

1. Based on the amount of BOD to be removed per day, calculate the gross amount of sludge synthesis.

2. Based on the amount of sludge to be carried under aeration, calculate the sludge age and the daily destruction of sludge. (At zero sludge age the volatile suspended solids content of activated sludge is estimated at 92 per cent.)

3. The difference between these quantities is the net daily production of sludge due to biological activity within the system.

4. The net production of excess sludge is calculated by accounting for suspended solids in the influent and effluent; that is,

$$\begin{aligned}\text{Excess sludge production} = {} & \text{gross sludge synthesis} - \\ & \text{sludge oxidation} + \\ & \text{solids in influent} - \\ & \text{solids in effluent} \quad \ldots\ldots \quad (2)\end{aligned}$$

Excess sludge from a contact stabilization treatment system is putrescible but relatively highly oxidized. There-

fore, aerobic sludge digestion is probably the most feasible and economical sludge digestion procedure. This is particularly true of small plants (1.0 mgd or less).

Sedimentation

General experience and specific industrial waste pilot-plant data indicate that the activated sludge of sludge reaeration processes settles better than that from conventional processes. However, the differences do not appear to be sufficiently great to justify higher sedimentation tank overflow rates.

These processes may have unusual sedimentation problems in some cases. Processes with short contact-aeration times treating wastes of high ammonia content may present sludge flotation problems due to denitrification. In any case, reasonable precautions should be taken to reduce sludge retention times.

Sludge recycle rates should be designed for considerable flexibility. Capacity rates of 50 to 60 per cent of the forward flow rate are recommended. Normal recycle rates will be 25 to 35 per cent.

Summary

Sludge reaeration processes can be designed from laboratory batch treatment data. This is true of any activated sludge process. The process provides an economical, flexible, and rugged system for wastes susceptible to high initial BOD removal (that is, high removal on contact). Sanitary sewage is in this category. The process is low in first cost because it requires minimal aeration volumes. It is rugged because it maintains a large reservoir of activated sludge solids out of contact with the waste being treated. The process is particularly suited to increasing the treatment capacity of existing plants at low capital cost.

For convenience, definitions of the symbols used in sludge reaeration calculations are included in the Appendix.

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APPENDIX—SYMBOLS USED IN SLUDGE REAERATION CALCULATIONS

a = Portion of BOD removed that is synthesized to activated sludge;

fb = Product of activity coefficient and enzyme concentration in relationship $L_{ri} = fb\, L_0\, S_0$;

k = BOD removal coefficient in relationship

$$\log\left[1 + \frac{aL_r}{1.42S_0}\right] = kt;$$

L_e = BOD remaining under equilibrium removal conditions, mg/l;

$L_0 = L_i$ = initial BOD concentration mixed liquor, mg/l;

L_r = BOD removal, mg/l;

L_{ri} = BOD removal on contact with activated sludge (that is, initial removal);

L_w = BOD of waste, mg/l;

r_e = BOD removal rate, per hour,

$$= \frac{L_0 - L_e}{L_e t_e};$$

S_0 = Activated sludge mixed liquor suspended solids concentration, mg/l;

t_e = Aeration time, in hours, required to reach BOD removal equilibrium; and

t_a = Aeration time, in hours, required to oxidize BOD materials complexed with activated sludge on contact with waste (that is, time to oxidize L_{ri}).

BDSA APPOINTS RISLEY

Roger E. Risley, Vice-President and Director of Engineering, Dresser Manufacturing Division, Dresser Industries, Bradford, Pa., is shown (right above) being sworn in as Assistant Director for Mobilization Planning, Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, U. S. Department of Commerce, Washington, D. C., by Acting BDSA Administrator Thomas E. Drumm, Jr.

CONSTRUCTION AND OPERATION OF THE PITTSBURGH PROJECT

John F. Laboon

Inasmuch as the Pittsburgh sewage works project has been described in recent publications (1) (2) (3) (4) (5) (6) (7), there is no need to repeat here its design features except briefly to generalize that the project (*a*) serves 71 municipalities, including the City of Pittsburgh, with a total present population of 1,200,000; (*b*) consists of a 150-mgd sewage treatment plant using the flotation method for concentrating primary sludge, plus 69 miles of intercepting sewers, of which 30.5 miles are in tunnel; (*c*) costs $100 million; and (*d*) is being financed by revenue bonds to be redeemed by sewage charges. The project was placed in operation April 30, 1959. The service area is shown in Figure 1.

An extraordinary safety record was made during the more than three years of construction. Only two fatalities were suffered; both occurred on the same day and, by coincidence, bore the same surname. One occurred in a tunnel as the result of a derailment, the other in a completed surface manhole which the workman entered without testing for the absence of oxygen.

Construction—General

Bids were taken on 34 contracts in December 1955; 32 contracts totaling $78,275,000 were awarded in February 1956. Two of the contracts were readvertised and bids were taken later on these and five lesser contracts totaling $2,040,000. The grand total of all contracts was $80,315,000. The final construction cost of the project, including a few minor contracts remaining to be paid off, is $82,533,000. The contracts called for completion within three years, or by March 1, 1959. Strikes and labor disputes, however, delayed the completion several months.

Construction of Open-Cut Sewers

The open-cut work involved sizes ranging from 8 to 54 in. The small diameter pipe was used exclusively for connections between small sewer outfalls and the main intercepting system. The latter ranged in size from 12 to 54 in. Cast-iron was used in the small sizes for river crossings, and asbestos-cement and clay elsewhere up to and including 20-in. diameter. Machine-made concrete pipe was used in 18-in. size and cast concrete pipe for all sizes 24 in. and greater. Authority experience with 18-in. machine-made concrete pipe was less than satisfactory. The 18-in. machine-made pipe was manufactured in 4-ft lengths with bell-and-spigot joints, the 24-in. cast concrete in 12-ft lengths, concrete pipe in sizes larger than 24 in. was cast in 16-ft lengths. All cast concrete pipes were provided with steel-end rings and circular rubber gaskets for watertightness. Diaper-poured cement joints were used for all sizes, including steel-end ring type, with complete satisfac-

John F. Laboon was Executive Director and Chief Engineer of the Allegheny County Sanitary Authority until August 31, 1960, when he retired and was appointed as consultant to the Authority.

The paper was presented at the 33rd Annual Meeting of the Water Pollution Control Federation in Philadelphia, Pa., October 2–6, 1960.

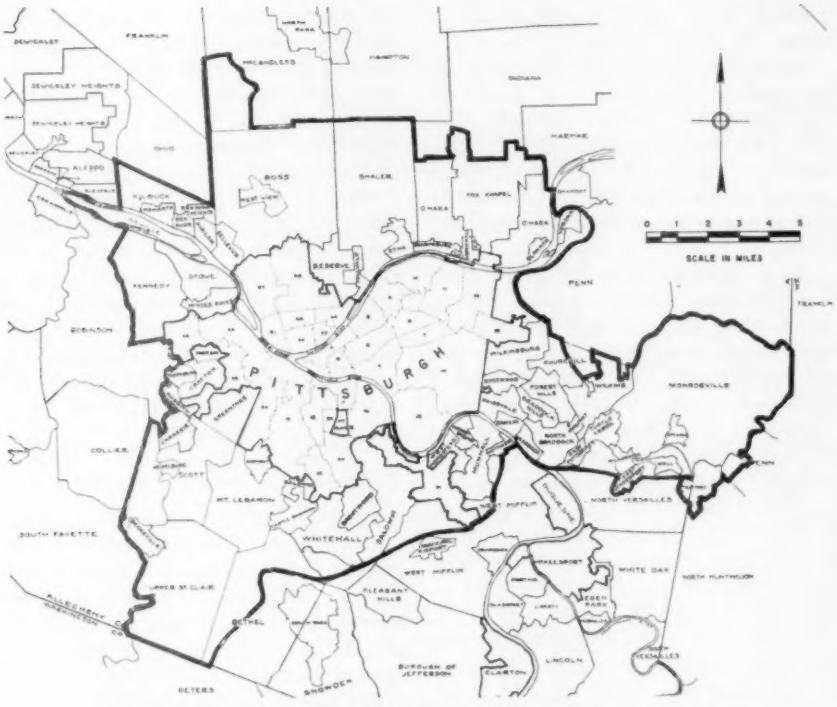

FIGURE 1.—Service area of Allegheny County Sanitary Authority.

tion. A minimum bedding of 6 in. of granulated slag was specified for concrete, asbestos-cement, and clay pipe laid in dry earth or rock trenches, and ¾-in. gravel bedding for cast-iron lines. Where very wet conditions were encountered, ¾-in. crushed slag or gravel bedding was substituted for granulated slag. The granulated slag in a short time cemented to a hardness approaching lean concrete. Of all concrete pipe in all sizes, 0.5 per cent was tested for strength and density, and 1 per cent was tested for infiltration. All tests were made at the place of manufacture.

Accelerated erosion tests using a sandblast machine, conducted on concrete pipe manufactured by various processes, indicated that the single factor providing greatest resistance to erosion was high-quality concrete, made with hard aggregates, the concrete properly cured and having a crushing strength of 7,000 psi. Precast concrete liner pipe possessing such qualities was adopted for all tunnel work, and concrete pipe of the same quality was adopted for open-cut construction in sizes 24 in. and larger.

Recently the Authority completed a section of intercepting sewer using reinforced concrete pipe with a new type of joint consisting of round rubber gaskets and reinforced fiberglas collars. The size ranged from 24 to 27 in. Each joint was made up of spigot-end pipes and two rubber gaskets fitting into the collar. Because of difficult soil conditions, the collar had a tendency to split circumferentially upon slight movement. The line met the specified infiltration test only after the leaky joints were calked with a special compound from inside the pipe.

Specified permissible infiltration for

various types of pipes and joints is shown in Table I.

Tests for infiltration in every instance met the specifications. The steel-end ring joints were particularly effective. An average example is a 9,488-ft section of 54-in. pipe in tunnel which on test produced an infiltration rate of 0.33 gpm as compared with a specified allowable rate of 1.67 gpm.

An unusual situation developed when concrete pipe actually parted at the same point that the concrete encasement parted due to contraction. It was concluded that the heat of hydration produced by the concrete encasement caused the cracking of both the encasement and encased concrete pipe. Expansion joints were provided in all concrete encasement placed afterward in open cut. The same experience developed in a section of 54-in. concrete tunnel pipe where grout containing as much as 10 bags of cement per cubic yard was used for backfill as a substitute for specified minimum 5.36-bag-cement concrete. Thereafter, permission to use grout backfill, which was costlier to the contractor, was refused and concrete backfill was kept at the minimum cement content specified. Fly ash was also permitted in limited quantities to reduce the heat of hydration. Stresses and strains in concrete pipe in tunnel under various conditions of backfill were determined by tests over a period of several months. These tests demonstrated that "the measured pipe strains agree in magnitude with those that would be calculated on the basis of the observed concrete and pipe wall temperature changes." Measurement of uplift forces in concrete backfill indicated the equivalent fluid weight to be two-thirds of the weight of concrete under the test conditions of slump and pumping for a 54-in. pipe.

TABLE I.—Permissible Infiltration

Pipe Type	Size (in.)	Max Infiltration (gpd/in. diam/mile)
Precast tunnel liner	all	25
Precast concrete in trench	24 and larger	50
	less than 24	150
Asbestos-cement	all	150
Clay	all	500

Most of the open-cut work was located in or immediately adjacent to streams where exceedingly wet conditions were encountered. Six subaqueous and six tunnel crossings of the major streams (the Allegheny, Monongahela, and Ohio Rivers) were constructed, in addition to numerous subaqueous crossings of Turtle and Chartiers Creeks (see Figure 2).

Construction of Tunnel Sewers

The most difficult construction was in tunnel. Most of the tunnel work was in rock, which did not present a serious problem. However, long sections were in mixed face of rock and sand and gravel, and in some cases fill-ground, requiring the use of air. Water and gases were challenging problems. A number of explosions resulted from carelessness on the part of labor and some were caused by unforeseeable circumstances. Fortunately, there were no fatalities on this account, although some serious injuries resulted. In one instance, carbon monoxide was discharged by air pressure into surrounding porous ground as far as several hundred feet from the tunnel construction, entering apartment buildings and homes by way of cracks in the floors and walls, and requiring complete evacuation of the apartments over a period of two months. Casings were driven into the ground near the tunnel line to relieve gas pressures. This method helped, but not sufficiently to relieve the condition in the dwellings. A serious delay in completion of this portion of the project resulted.

Other odd situations developed elsewhere. A 10-in. water line was encountered crosswise of a tunnel being driven under a railroad yard through

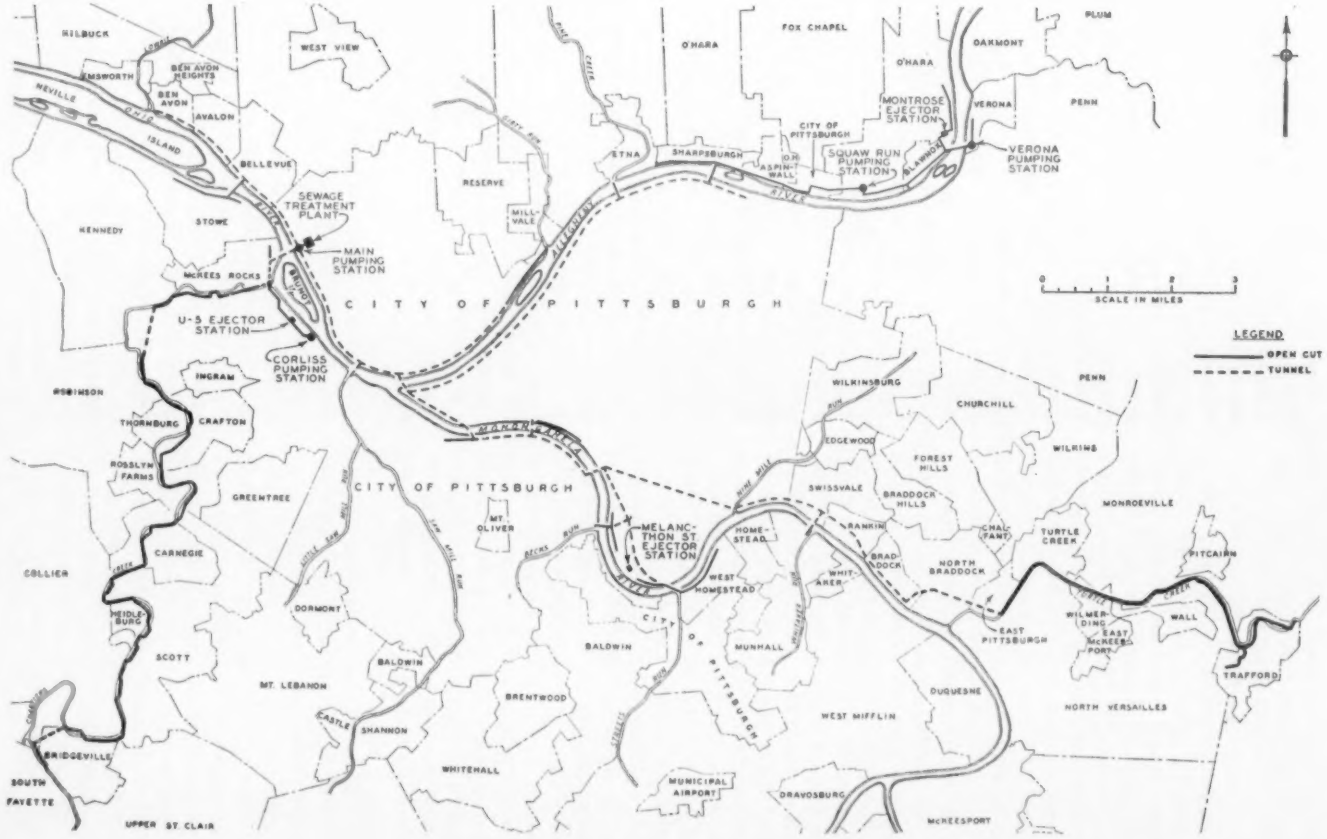

FIGURE 2.—Plan of intercepting sewer system.

an old fill 40 ft deep. The water line had to be relaid the width of the tunnel. A gas-well casing was encountered in a tunnel immediately under Gateway Center in the "Point" or "Golden Triangle" section of the City. In another case, excavation of the tunnel lowered the groundwater level to the point where oil dumped on the surface drained into the tunnel. In a deep tunnel under a steel mill hot water was encountered in a persistent stream which kept the tunnel atmosphere at 100°F. A coal seam was encountered in a tunnel crossing of the Ohio River.

Five tunnel muckers working on the night shift under air pressure of 14 psi suddenly found themselves trapped in an air lock at 3:00 AM when a bulkhead failed and caused flooding of the entire system of tunnels. A head of 17 ft of water against the door of the air lock prevented escape. Small pumps were available, but they would have taken too long to dewater the many miles of tunnel. The wet well at the main pumping station also was flooded. Only one of the 60-mgd main sewage pumps was electrically connected for operation, but it had not been turned over as yet. Furthermore, the motor had been accidentally wetted by a broken water line and had not been dried out. There was fear of damage to the pump and motor. In desperation the order was given to start the pump. It worked. One hour and 20 min later the men walked out of the air lock visibly relieved. A fatal accident was narrowly averted by a fortunate turn of circumstances.

The size of pipe in the tunnels ranged from 30 to 126 in. Water infiltration into the tunnels during construction varied with the conditions. Water pumped from a tunnel excavation for pipe ranging from 54 to 126 in. averaged 250 gpd/ft over a period of 24 months. This was the greatest. The least was pumped from a tunnel for 36- to 60-in. pipe. The average was 85 gpd/ft over a period of 20 months.

Both the Dravo Corporation and Perini Corporation tried boring holes for the tunnels by means of Robbins boring machines, the patents for which were controlled by Goodman Manufacturing Company. Their use was abandoned because of operating difficulties and the high cost of maintenance of the cutting bits. However, the short sections of bored tunnel, totaling 131 ft, were beautiful to behold. Conventional methods were used in the remainder of the tunnel construction.

All tunnel mining required completion before the precast concrete liner pipes could be inserted. Several ingenious methods were used for lowering the pipes in the shafts and then heading them into the tunnel openings. Because the sections of the largest size pipe weighed as much as 40 tons each, they were not easy to handle. The largest size required specially constructed carriers for hauling to the job.

Lock Joint Pipe Company, the subcontractor for casting of the larger sizes (72 to 126 in.), set up a plant on a rented site located 15 miles from the Golden Triangle. A feature of the plant was the use of an automatic machine for welding reinforcement of the 126-in. pipe.

Allegheny Concrete Pipe Associates, now controlled by American-Marietta, manufactured the smaller sizes (up to 66 in.) at two different plants.

All pipe was steam-cured under accurate controls. On completion of casting, the pipe was covered with a tent and heated with steam to 110°F (max 150°F) gradually over a period of 4 hr. The temperature was maintained for the next 4 hr, then reduced gradually to atmospheric temperature over the final 4 hr. The forms were then removed and the pipe was transferred to the water-curing tent where wet steam was condensed to maintain temperatures of about 70°F for a period of 6½ days.

Concrete backfill was placed by pumperete and pneumatic equipment.

The pours were limited to three 16-ft sections of pipe, requiring a temporary timber bulkhead with each pour. Sometimes a permanent bulkhead was used consisting of sacks filled with sand and cement which were concreted in place. The slick lines were kept buried. Water from the roof was either panned or piped; if piped, the pipes later were backgrouted. Careful control of the size and character of sand aggregate was most important for successful pumping of concrete. Exacting control of the water-cement ratio was also necessary to avoid segregation of aggregates and consequent plugging.

Construction of Sewage Treatment Plant

The site of the sewage treatment plant, located within the City of Pittsburgh 3 miles downstream from Gateway Center (the Golden Triangle) (Figure 1), was formerly occupied by two steel mills that were abandoned and cleared from the site many years ago. More than 10,000 cu yd of old foundations were uncovered and removed to make room for the new plant foundations. Strangely, not one of the preliminary borings penetrated any part of the old foundations to indicate their presence. The borings clearly indicated that the substrata to an appreciable depth consisted of fill materials such as slag, cinders, and steel mill debris overlying river silt, sand, and gravel. Rock was shown to be approximately 50 ft below the surface. The incinerator building, the administration building, the blower room, the chimney, the rack and chlorination building, and the grit chambers were constructed on piles.

The large area of preaeration and sedimentation tanks had been designed originally with pile foundations. However, following a soil study it was decided to substitute for the costly piling a 3-ft bed of granulated slag rolled in 18-in. layers on which the structures were founded. Sisalkraft paper was placed over the slag to prevent leaching of water from the concrete mix. The maximum settlement of the tank walls on test with the tanks full of water for a period of 30 days was $\frac{3}{8}$ in. No evidence of settlement cracks was found after the test.

Liberal quantities of copper expansion joints and steel waterstops were used to assure watertightness. At first tank walls were poured in 90-ft sections, but this later was changed to less than 45 ft to avoid contraction cracks.

One of the most interesting and sensational pieces of construction was the pumping station, including the wet well in the center. The excavation was made through 50 ft of earth overburden before rock was reached. The outside diameter of the pumping station is 100 ft; the excavation was approximately 106 ft in diameter. The excavation in earth was very wet, especially at the top of the rock where a bed of overlying gravel was encountered. Sheet steel piling was driven to rock and ribbed with circular beams for support without any bracing whatsoever. At the time, it was claimed to be the largest such excavation ever constructed in this manner. Excavation continued through 72 ft of rock, unsupported, but wet. The 5-ft reinforced concrete bottom slab was anchored to the rock by means of No. 11 bars grouted in place to counterbalance hydraulic uplift.

The requirement for watertight walls in the deep pumping station made it necessary to pour them in such a manner as to keep the concrete free of groundwater. This was accomplished by placing overlapped corrugated-iron sheets against the excavation so as to confine the water to the space between the sheets and the excavated face. The concrete was then poured against the sheets as one side of the wall form. The sheets were pressed against the rock by the concrete as it was placed, but sufficient space was left behind the sheets for the water to flow downward

to a pump sump. In this manner the concrete was kept free of excavation water during pouring. After the outside walls were poured, the space between the excavated face and the corrugated sheets was pressure grouted. A watertight wall was the result.

The 40-ft inside diameter wet well, located in the center of the pumping station, extends the full height and is concentric with the outside walls, thus forming an outside annular space in which the main sewage pumps are located. In addition to the main pumping station, the project includes three local pumping stations and three lift stations (Figure 2). The capacity of the largest local pumping station is 6 mgd.

Operation of Project—General

The operation of the entire project is under the supervision of the general superintendent. Four shift superintendents are assigned to shift work at the sewage treatment plant and another superintendent heads up the operation and maintenance of the intercepting sewer system. At the start of operations in 1959, only three engineers on the staff had had any experience in sewage treatment. Only one of the non-technical personnel had such experience. The start of operations and the tuning-up of the plant were therefore rendered more difficult. The training of personnel had to be done in step with the conduct of operations. The staff and operators responded to the challenge, and to their credit operations continued without interruption.

The sewers of the City of Pittsburgh are of the combined type. Although the great majority of the sewer systems in the smaller municipalities are of the separate type, none is free of surface drainage contributed largely by roof conductors. Therefore, diversion structures for storm overflow have been provided at every connection made to the Authority system; in all, 321 sewer outfalls have been connected.

Industrial wastes create problems which must be solved one way or another. This can be done successfully only by means of adequate controls. For this purpose a division of seven samplers or investigators, headed by a sanitary engineer, has been established to cope with special situations and to inspect and sample the 321 sewer outfalls connected to the system. This same group also investigates immediately all odor complaints.

The investigation and study made in 1946 and 1947 included weir measurements and analyses of sewage from 35 sewer outfalls representative of the county-wide project, which involved an area much greater than the present abbreviated project covers. The quantity of sewage from the measured outfalls totaled 64 mgd. Studies of the resulting data led to the conclusion that the sewage treatment plant should be designed to treat raw sewage possessing 275 mg/l of suspended solids and 300 mg/l of BOD. The average values for 12 months of operation, beginning with August 1959, are 207 mg/l of suspended solids and 139 mg/l of BOD. The latter do not include screenings, grit, and grease balls. Four factors served to affect the design assumptions in comparison with actual values: (*a*) the 30 municipalities which decided to go their own way and not participate in the Authority program were largely residential and served by separate sewer systems; (*b*) most of the City of Pittsburgh sewers are large and combined and flooded under normal conditions to depths as great as 15 ft, thus making it impossible to meter and sample the sewage flow at the outlets (this required placing the weirs some distance from the river, thus excluding much of the flow from industry located along the river banks); (*c*) the old submerged outlets which formerly discharged into the rivers under backpressure are now emptying into the intercepting system; thus, the backpressure has been completely re-

lieved but the diluting effect of infiltration has increased; and (*d*) the pretreatment of certain industrial wastes before acceptance by the Authority.

The preliminary report of the county-wide project issued January 1948 has this to say about the degree of treatment necessary to produce oxygen balance in the Ohio River:

> A 50-per cent removal of the organic pollution in the composite sewage would reduce the BOD to approximately 150 mg/l, and for proper dilution with the river waters of the Ohio, the required river flow is a minimum of 3,500 cfs. According to the U. S. Engineer Office river records, such dilution is available in the Ohio River at the point of proposed effluent discharge 98 per cent of the total time with present low water regulation by the flood control dams.

Since publication of the 1948 report, low flow regulation of flood control reservoirs has added 1,000 cfs to the Ohio River upstream of the treatment plant, thus affording even greater dilution of the plant effluent. The Kinsua Dam, now under construction on the upper Allegheny River, will further augment the dilution factor. In any case, the treatment plant under present conditions is more than adequate to meet requirements of oxygen balance in the Ohio River.

Operation of Intercepting System

The surface structures of the intercepting sewer system include 122 downshafts; 258 diversion chambers for stormwater overflow, of which 146 are of the automatic, unbalanced leaf, tipping type and the remainder are equipped with double orifices, single orifices, and pipe-type orifices; 10 tunnel shafts equipped with telemeter transmitters; and 6 lift and pumping stations, all of which require constant maintenance. Some diversion structures located along the rivers are accessible from the riverside only, thereby requiring a boat and work barge on which are transported pumps, compressors, and other equipment neces-

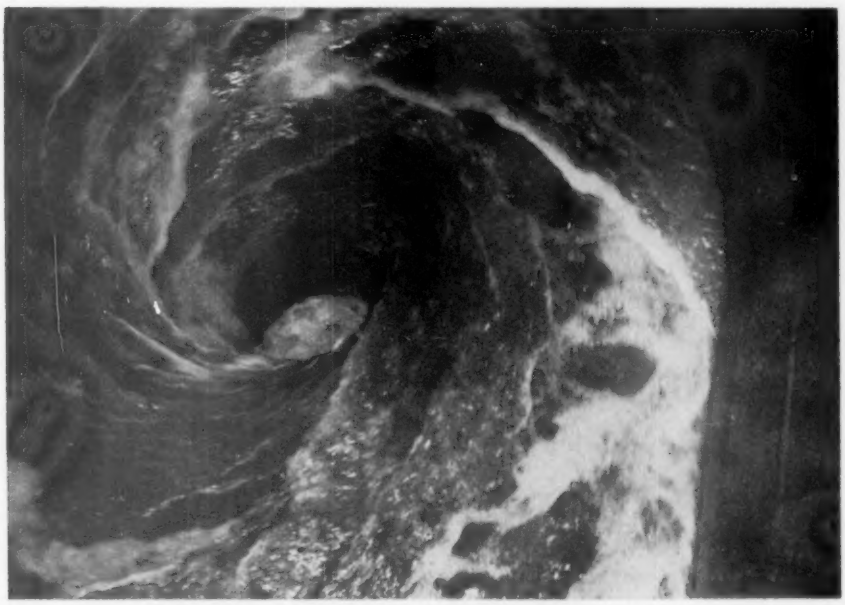

FIGURE 3.—Large vortex chamber leading to downshaft.

FIGURE 4.—Small vortex chamber leading to downshaft.

sary for proper maintenance. Five maintenance crews, provided with trucks fully equipped and each manned by a three-man crew, make their daily rounds to check backwater gates and automatic tipping gates; to clean the screens in the pumping stations; and to provide other required maintenance. Dredges are employed at frequent intervals to remove the grit deposited in front of the diversion structures during storm overflows.

The downshafts with their vortex entrance chambers (Figures 3 and 4) have been operating according to design without any difficulty whatsoever. The system of submerged control of the tunnel intercepting sewers has been successful and economical. The telemeter system is designed to transmit levels of flow at each of 10 tunnel shafts strategically located throughout the system. The purpose of the telemeter system is (*a*) to provide prompt notice of increased flows caused by local storms or other conditions; (*b*) to indicate storm overflow when it occurs at two major control points; and (*c*) to show on the central control panel located in the main pumping station the hydraulic gradient throughout the system, especially during weekly drawdowns.

Operation of Sewage Treatment Plant

Odor

The first year of operation of any sewage treatment plant requires many adjustments, and the Pittsburgh plant (Figures 5 and 6) was no exception. It was determined at the start of operations that there would be no interim shutdowns of the system to permit convenient adjustments. The system was to remain in operation at all times, if only in part. Many things plagued the staff. The percentage of volatile solids of primary sludge soon after the start dropped into the 30's. The primary sludge, containing as much as 15-per cent solids, could not be pumped

except at reduced rates; as a result, the sludge blanket in the sedimentation tanks accumulated to excessive depths and became septic.

Sludge odors developed in the gases discharged from the stack immediately on starting the furnaces. Increasing the furnace temperatures in an attempt to destroy these odors merely fused the sludge and coal ashes, with the result that molten slag built up in the furnaces in such quantities as to require frequent shutdowns for manual removal—it could not be sluiced. (Coal is required to supplement the Btu content of concentrated sludge so that combustion may be sustained. The incinerators are required to destroy concentrated sludge having a specified average solids content of 18 per cent. The specifications required a minimum deodorizing temperature of 1,250°F, but did not state where the temperature was to be measured or into what part of the furnaces the odorous vapors were to be discharged.) Finally, after waiting almost six months for abatement of the sludge odors in the stack effluent, the incinerators were closed down on October 27, 1959.

In the meantime, other parts of the plant not affected by the shutdown continued in operation. Sewage was pumped; screenings, grit, grease and grease balls were removed and disposed of; and aeration and chlorination were applied. The raw sewage was aerated and bacteria were destroyed. The contractor began to modify the incinerators. The metal partition between the combustion air and the vapor return chambers was insulated with plastic material to stop short-circuiting of combustion air into the vapor chamber; the chamber at the top of the preheater tubes was provided with soot blowers; the water level in the ash-sluicing pit inside the furnace was lowered 18 in. to reduce vaporization and to provide greater effective volume in the combustion chamber; and most important of all, the odoriferous drying vapors were rerouted via four new ports, each 2 ft by 5 ft, cut through the

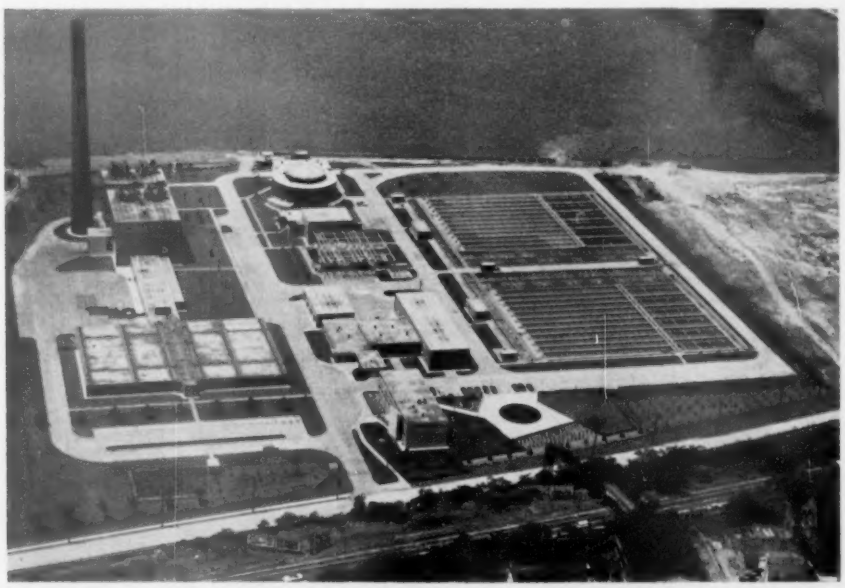

FIGURE 5.—Sewage treatment plant of Allegheny County Sanitary Authority.

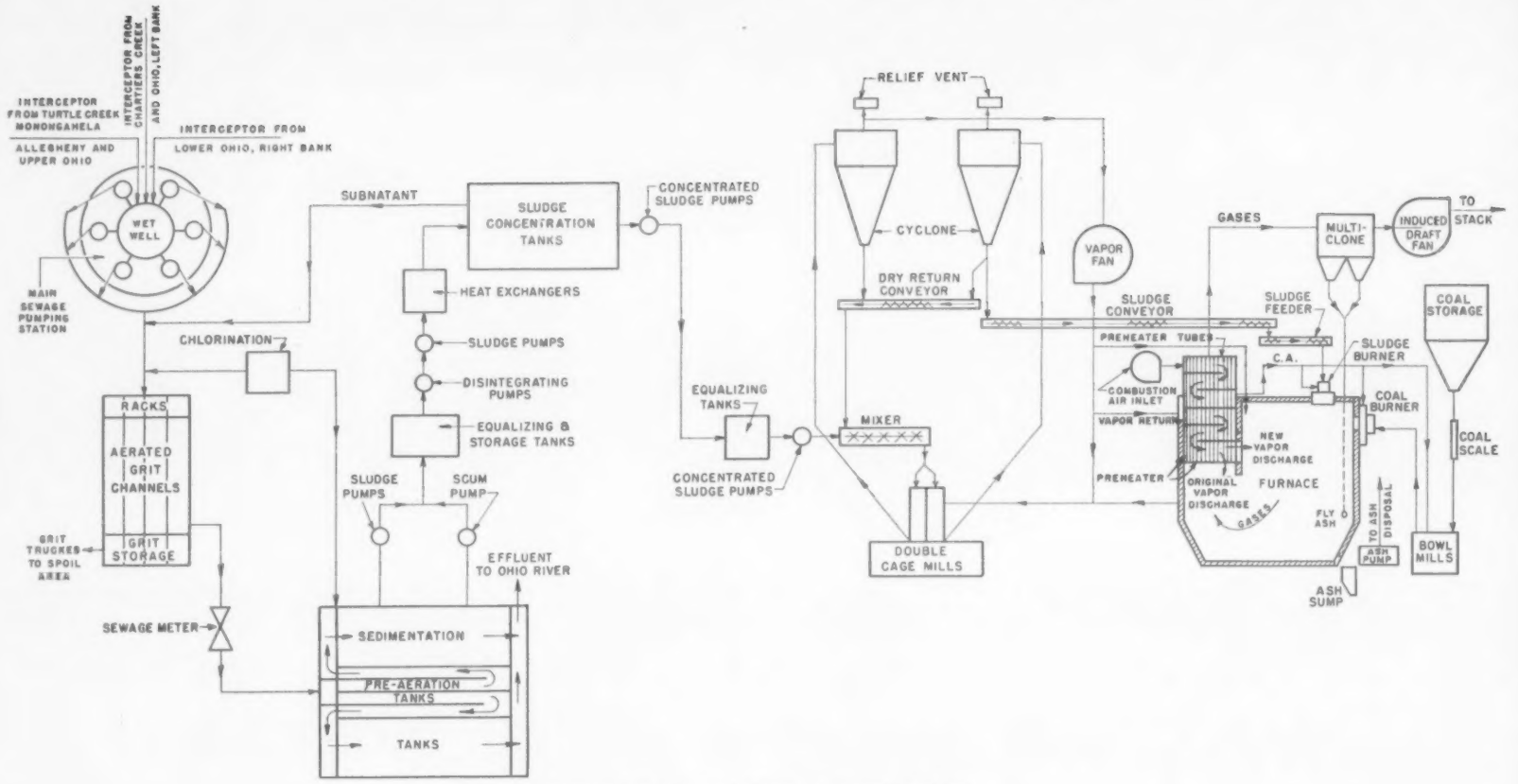

FIGURE 6.—Flow diagram of treatment plant.

target wall so that discharge of the vapors was now directed into the hot flames in the combustion chamber. On completion of the modifications in one furnace, operation of the incinerator was resumed on February 2, 1960.

The effects were immediate. The sludge odors were gone. Complaints ceased, except that the experience with stack odors from the treatment plant had made the public odor-conscious and the sewage treatment plant was still being blamed on occasion for odors emanating from other sources, industrial and even burning garbage dumps. Slagging in the furnaces is no problem now, and ash sluicing is not a task to be dreaded. Helicopter flights through the gases discharged from the stack confirmed the absence of sludge odors. The remaining three furnaces have been similarly modified.

At present, undue vibration has developed in the vapor fans, caused by deposits on the fan blades and casing. This condition requires laborious scraping off of the deposits in uncomfortable quarters and temperatures. Experiments now under way may bring about a solution.

Pumping

The wet well located in the center of the pumping station is operated under

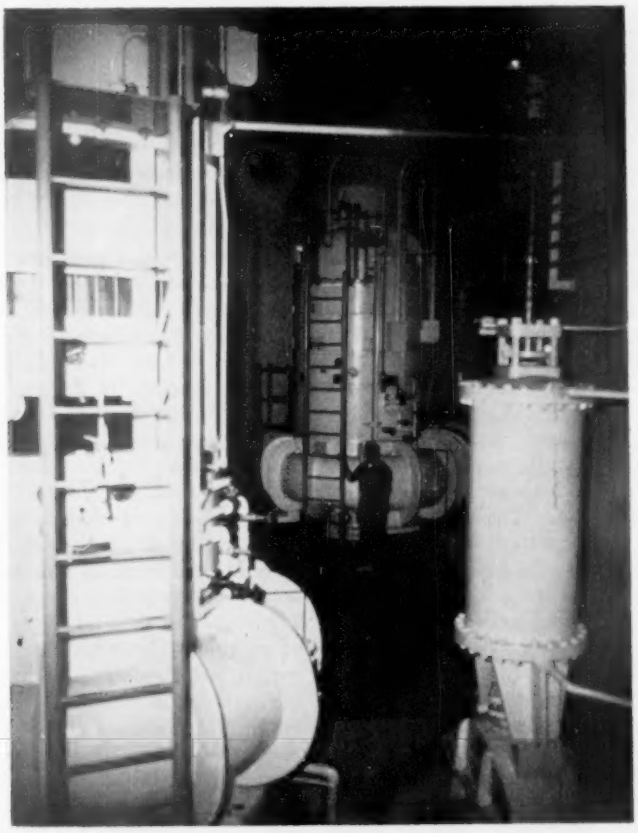

FIGURE 7.—Discharge risers in dry well of main pumping station with sewage pump in background.

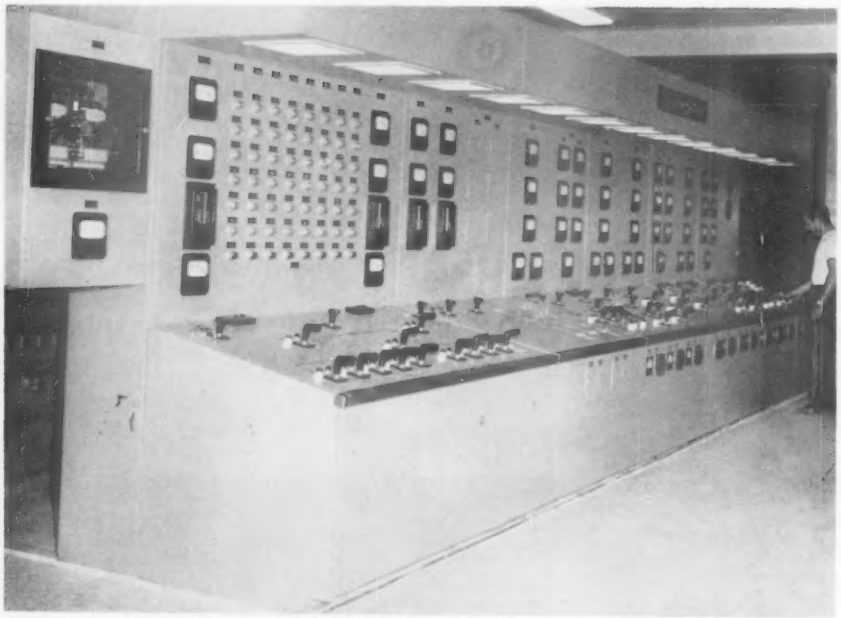

FIGURE 8.—Duplex control benchboard in control room of main pumping station.

submerged control, which keeps the tunnel system completely flooded. The static head on the suction side of the pumps is normally 72 ft. The wet well, including the entire tunnel system, is pumped down once a week beginning about Saturday midnight. This goes on for 16 hr before the system is gradually submerged again to normal levels. Considerable quantities of grit, screenings, and grease balls are removed during this operation. The lowest level of sewage at maximum drawdown reaches a point 4 ft above the invert of the 126-in. tunnel, which is 74 ft below normal submergence. The net pumpdown is 70 ft.

Three two-speed pumps (Figure 7), each having an individual capacity of 50 mgd at maximum drawdown level, pump a total of 142 mgd at this level when all three are in operation. The two variable-speed magnetic drive units can be used during the first 52 ft of drawdown to a level 22 ft above the invert of the 126-in. tunnel, and not at lower levels. The velocity of flow in the system during drawdown reaches a calculated maximum of 4.4 fps. Figure 8 shows the main control panel.

A sixth pumping unit is now being installed to serve as additional reserve capacity, especially during drawdown periods. The need for another two-speed unit was emphasized when a most unusual accident occurred early in 1960, causing a short-circuit in the 1,250-hp motor of one of the two-speed units and making impossible any effective drawdown of the intercepting sewers for a period of three months. The variable-speed units are ineffective at maximum drawdown. During this period, a 5-ft blanket of heavy grease accumulated at the flow line in the wet well. This blanket finally had to be removed by hand.

Present operation during storm flows calls for a permissible maximum pumpage into the plant of 225 mgd. This represents the calculated wet-weather peak flow according to a hydrograph

prepared on the basis of an assumed general rainfall covering the whole service area and with overflow structures operating according to design. The excess over the 225-mgd rate causes the wet well level to rise, and the intercepting sewer system to overflow at the various diversion structures in conformance with the storm-flow hydraulic gradient. Automatic control of pumping units is changed over to manual control during this period.

Screening

The four mechanical racks have been subjected to severe usage due to the deposit of bricks, stones, beer cans, sand and gravel, coal, and even parts of automobiles in front of and behind the screens, causing the rake teeth to bend and break and even to shear off in whole sections. Installation of a plyboard guide vane in the entrance channels of the two end screens has improved the situation materially, but something more is desirable. The Carnegie Institute of Technology has been engaged to conduct model tests in its hydraulic laboratories, not only on the rack channels, but also on the aerated grit chambers to determine the most effective channelization of these units.

The quantity of screenings removed has been below design estimates, averaging 0.75 cu ft per million gallons. The clear space between bars is 1 in. Experience indicates that the bars, which are 2 in. by ½ in. in cross-section, are too light for the long span between top and bottom supports. It is proposed to install new bars 4 in. by ½ in. in section. The screenings after draining are dumped into tightly covered garbage containers and hauled to a privately-owned sanitary fill for disposal. Comminutors were not installed in this plant.

Grit Handling

The four aerated grit chambers have performed fairly well. Distribution of grit throughout the channels has not been as uniform as was expected. In the beginning there was obvious short-circuiting of flows through the grit chambers. This was arrested by installing a deflector baffle at the influent end. A 6-in. grid 6 in. deep was installed at the bottom of the baffle to arrest horizontal undercurrents. The effluent end was also provided with a round-the-end baffle having a solid bottom.

Design of the grit chambers provided for aeration at the rate of 5 cfm per

TABLE II.—Typical Weekly Screen Analyses of Composited Grit Chamber Deposits

Channel No.	Date* (1960)	% Retained on					% Passing No. 100 Mesh
		No. 20 Mesh	No. 40 Mesh	No. 60 Mesh	No. 80 Mesh	No. 100 Mesh	
2	6/22	36.3	21.7	21.4	11.8	4.2	4.6
	6/30	46.4	24.9	16.9	7.1	2.2	2.5
	7/8	34.8	29.0	22.5	8.1	2.8	2.8
3	6/22	42.0	21.2	19.1	10.0	3.3	4.4
	6/30	36.3	24.3	22.4	10.8	3.6	2.6
	7/8	35.9	23.4	19.9	11.4	4.7	4.6
4	6/22	73.6	15.3	6.7	1.9	0.6	1.8
	6/30	47.5	23.2	15.5	7.6	2.9	3.3
	7/8	38.9	22.2	20.4	10.4	4.2	3.9

* Inches of rainfall (County Airport readings): 6/21, trace; 6/22, 0.24; 6/23, 0.0; 6/29, 0.59; 6/30, 0.0; 7/1, 0.68; 7/7, 0.0; 7/9, 0.0.

lineal foot of channel. Application of air has been adjusted to various rates of flow in an attempt to improve the distribution of grit throughout the channels. Although improvement has been noted, the middle section of the grit channels still collects little grit, the major deposit being found at the influent end and the next large deposit at the effluent end. It is confidently anticipated that the proposed model study will help solve this problem.

Many screen analyses of grit have been made to determine the pattern of deposit in the channels. Experience shows that the two end chambers receive and deposit much more grit than the two center chambers and that the flow of sewage is difficult to distribute among the four chambers with any degree of equality in spite of the hydraulic sluice-gate controls available at both inlet and outlet ends.

Little data have been published on the subject of sieve analyses of grit deposits. Typical screen analyses of weekly samples are given in Table II. Typical screen analyses of grit deposited at the effluent end of Channel 2 are given in Table III.

The average production of grit during the months of February to August 1960, inclusive, since incinerator and boiler ashes have been excluded, was 1.7 cu ft per million gallons. The volatile solids of 114 samples analyzed during the summer months of 1959 averaged 26.9 per cent. In 1960, 109 samples during the same summer months averaged 16.0-per cent volatiles. The marked improvement in the 1960 results was brought about by improved operation. A true picture of volatiles representing organic pollution cannot be presented since the advent of cigarette filters, which to the eye appear in greater quantities than truly organic matter. Furthermore, in Pittsburgh volatiles are not representative of organic pollution alone due to the presence of appreciable quantities of coal and cinders, which drain into combined sewers from coal yards and highways.

TABLE III.—Typical Screen Analyses of Grit Deposited at Effluent End of Channel 2

% Retained on					% Passing No. 100 Mesh	Vol. Sol. (%)
No. 20 Mesh	No. 40 Mesh	No. 60 Mesh	No. 80 Mesh	No. 100 Mesh		
29.3	21.4	16.5	10.3	8.7	13.8	13.3

The design of the grit chambers contemplated 100-per cent detention of grit retained on a 100-mesh sieve. Although Table III indicates as much as 13.8 per cent of the sample passes the 100-mesh sieve, experience indicates that some grit passes through the grit chambers during storm flows. A metal cover for the overhead monorail carrier track is now being installed for protection from ice, snow, and rain.

The original design provided for sluicing of coal and incinerator ash to the four grit storage tanks located at the effluent end of the grit chambers so as to permit convenient draining and final removal to the dump site in company with the grit. This was a good idea, but it did not work as well as had been anticipated. The fine incinerator and fly ash would not settle as quickly as was necessary to accommodate the large quantities of sluicing water which kept the overflows busy. Lagoons have since been provided for coal and incinerator ash sluicing. The lagoons consist of a series of tanks which form the river wall bordering one side of the plant site. The tanks originally were designed as deep pockets for storage of coal for the steel mill which formerly occupied part of the site. The pockets were later filled with slag, which was readily excavated to provide lagoons for ash disposal. The arrangement is unusual and excellent for the purpose. The grit drainage and storage tanks are an indispensable adjunct to plant operations.

Preaeration

The preaeration tanks have been operated with air applied at the design rate of 7 cfm per lineal foot. Studies so

far fail to indicate that suspended solids removals are improved by preaeration. However, preaeration has performed two important functions; namely, to oxygenize the raw sewage from zero to almost 6 mg/l in the final effluent, and to coalesce greases for improved separation. Grease balls in unusual quantities collect at the surface at the end of the first pass of each tank, requiring laborious and messy removal by hand. This grease is disposed of, together with sticks and other floating material, in a privately-owned sanitary fill located two miles from the plant. To relieve the laborious handling, a combination trough and beach plate have been installed at the end of the first pass of each preaeration tank for more convenient removal of grease balls as well as floating grease and oils. The grease balls and other materials are now flushed to the scum tank. Sticks and the like must still be segregated. Four aluminum slide gates have been installed in each of the two tanks to permit bypassing either of the two batteries of sedimentation tanks when necessary. Studies are under way to determine the comparative efficiencies of spargers equipped with teflon orifice-inserts and standard spargers consisting of integrally-cast orifices as well as of orifices formed by short pipe nipples inserted in the air headers, and plain orifices without nipples. (The studies completed after presentation of the paper revealed serious clogging of all types of spargers due to iron deposits and calcination. The plant is now operating with plain and nippled-pipe orifices without difficulty.)

The three blowers, each having a capacity of 6,000 cfm, have functioned well. However, the noise in the blower room in the beginning was intolerable. Replacement of the spiral-riveted discharge piping with heavy welded steel, isolation of the snubbers from the floor by means of insulating pads, and sound-insulation of the piping and snubbers have provided the needed relief.

Sedimentation

The sedimentation tanks have functioned well with respect to the concentration of primary sludge, which at times has reached 15 per cent. The sludge pumps labored unfairly under such circumstances. The situation has been improved by installing 2-in. diluting connections to the pump suctions inside the tanks, using raw sewage as the diluent. Primary sludge is now watered down to 8 per cent at the start and pumped with complete satisfaction. The tanks are equipped with drag-type longitudinal conveyors with screw-type cross conveyors. Scum and floating ground garbage are other items requiring attention. The 8-in. scum lines serving the scum troughs have been replaced with 14-in. steel lines, with marked improvement in flow of scum to the scum tank. Scum is flushed to the scum tank and then pumped to the primary sludge holding tank. This is the first plant to be equipped with left and right revolving skimmers, which skim the scum over the beach plates and into the troughs. Adjustments to the beach plates and overflow weirs to permit more effective skimming during the full range of sewage flow are in progress. The operation of the new type skimmers when the beach plate is properly inundated has been very satisfactory. The composition rubber wipers are under study with a view to avoiding their curling at the wiping edge.

Sludge Handling

The sludge pumps were originally equipped with constant-speed motors, but overloading of the motors occurred as the result of initially low pumping heads and increased capacities, requiring their replacement with variable-speed units. Sludge density meters are being installed in the suction lines serving the six sedimentation tanks. A similar meter was installed recently in one of the concentrated sludge lines leading to the day tanks serving the

incinerators. Another such meter was installed at the same time in the settling tank discharge line. As the result of their highly satisfactory performance, it is believed their use as a guide to primary sludge pumping will materially improve operations. During pumping both primary and concentrated sludges (Figure 9) are analyzed continuously for density by means of moisture determination balances. The answer is available within 20 min. As a result the density meters are checked at these times.

The grease content of composited primary sludge averaged 14.1 per cent over a period of 58 days in July, August, and September 1960. The grease in corresponding concentrated sludge averaged 14.5 per cent. The increased grease content in the concentrated sludge is due to the addition of scum.

During the first year of operation the sludge lines gave no indication of any difficulty due to grease accumulation, but recently it was found that hard grease had lined the pipes to a thickness of almost an inch. Subse-

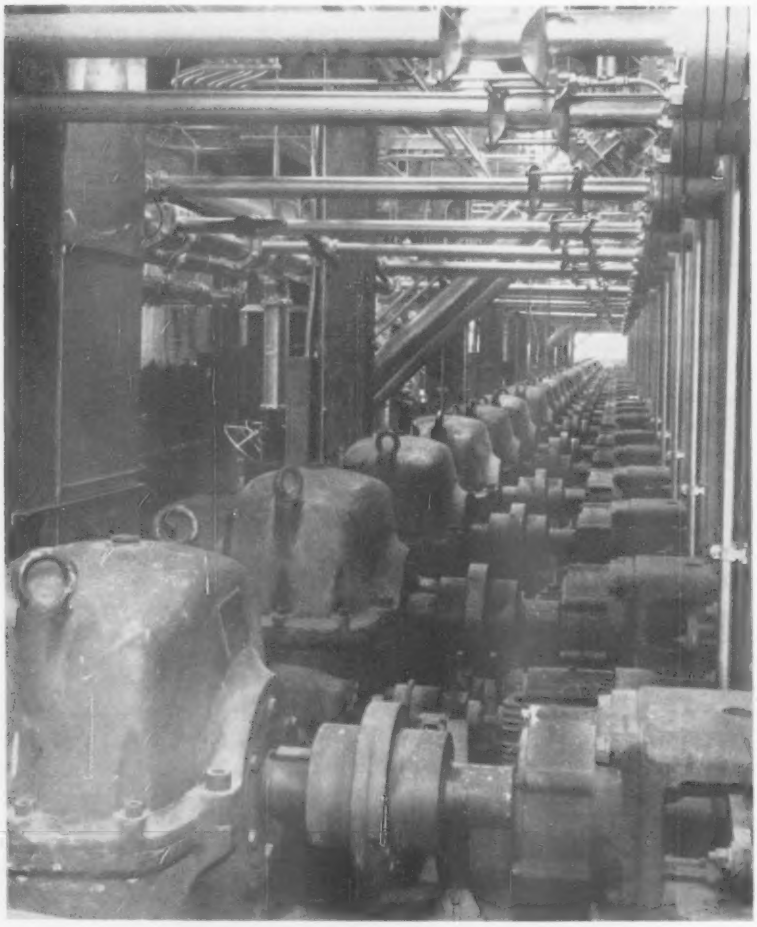

FIGURE 9.—Sludge concentration gallery.

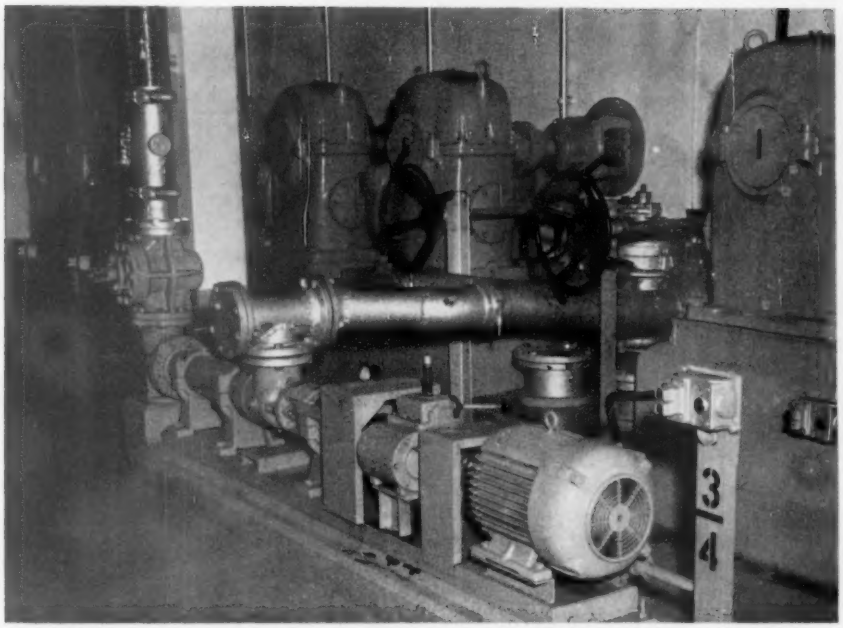

FIGURE 10.—Sludge disintegrators located in sludge concentration gallery.

quently, a warm water system for flushing the sludge lines has been installed, with good results. The lines are now flushed weekly.

The magnetic sludge meters originally installed in the two primary sludge discharge lines have failed to perform with any degree of accuracy. One has been returned to the manufacturer for study.

Primary sludge is pumped to a holding tank, from which the disintegrators (Figure 10) deliver disintegrated sludge to plunger pumps (Figure 11). The latter boost the sludge through the heat exchangers for heating to 95°F en route to one of the concentration tanks. An intermediate holding tank to receive the disintegrated sludge has been found unnecessary. The sludge disintegrators have been satisfactory. There has been no clogging whatsoever of the pumps serving these units.

After detention of primary sludge in the concentration tanks for five days the separated supernatant is withdrawn and returned to the influent side of the screen chamber for routine treatment. The concentrated sludge is pumped from two or more tanks simultaneously in order to blend the bottom and top sludges and thus produce a sludge of uniform consistency for purposes of incineration. The bottom of the mass of sludge, after the supernatant has been withdrawn, possesses a solids content of approximately 11 per cent. This prevails for only a few inches of depth before heavy concentration begins. This method of obtaining uniform concentrations over a 24-hr period has been highly successful. The concentrated sludge is pumped to the daily hoppers or holding tanks, one of which is provided for each of the four incinerators. The concentration tanks are divided into six channels, each served by a horizontal screw conveyor which feeds the concentrated sludge to a cross-collector screw.

Originally, a vertical screw was installed in each tank to lift the sludge

to a hopper located at the top of the tank from which the sludge flowed into an inclined pipe leading to the suction side of the sludge pump. The vertical screws failed to lift the sludge with any degree of certainty. They were finally removed. Now the pumps are connected directly to the tank sumps. The original theory was that the pumps would not operate under suction lift. This has been disproved. Fortunately, the original 8-in. supernatant lines could be converted into direct pump suction connections.

The cross-collectors have caused the most difficulty because of broken shafts. As often happens, necessity is the mother of invention. Recently, another cross-collector screw failed. The concentrated sludge in the tank with the broken cross-collector had to be removed for incineration. The tank was emptied completely without the aid of the cross-collector, except for approximately 500 gal, which remained in the cross-collector channel largely because of the retarding effect of the screw. Since that time, all concentration tanks have been emptied in a similar manner, except that the cross-collector screw has been used in the final few minutes to clear the cross-collector channel of sludge.

The cross-collector screw has been removed completely from one of the tanks to demonstrate the effectiveness of sludge removal without the aid of the screw. A major improvement in operating efficiency will be accomplished if the tests now under way prove that the removal of the cross-collector screws and attendant equipment from all concentration tanks is warranted. Thorough mixing is necessary for pumping highly concentrated sludges. This is accomplished with the use of the longitudinal screws. The resultant sludge possesses low viscosity and good flow characteristics.

The concentrated sludge pumps have

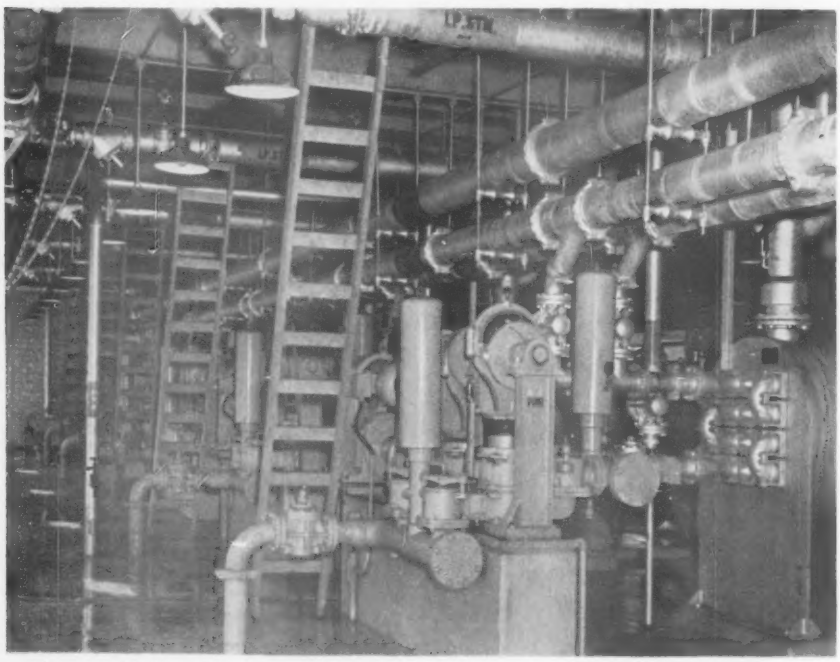

FIGURE 11.—Pumps and heat exchangers in sludge heater building.

TABLE IV.—Monthly Average of Daily Composited Primary and Concentrated Sludges

Date	Primary Sludge			Concentrated Sludge (Pugmill Samples)		
	No. of Compos. Samples	Total Solids, Avg (%)	Volatile Solids, Avg (%)	No. of Compos. Samples	Total Solids, Avg (%)	Volatile Solids, Avg (%)
May 1959	10	8.1	50.4	—	—	—
June 1959	20	15.1	45.4	20	22.2	44.3
July 1959	21	11.7	44.0	25	18.8	41.8
Aug. 1959	31	12.0	46.8	27	16.8	41.8
Sept. 1959	30	9.9	57.5	30	16.1	50.0
Oct. 1959	15	12.6	48.0	26	17.8	48.5
Average	(6 mo.)	11.6	48.7	(5 mo.)	18.3	45.3
Feb. 1960	27	9.3	61.5	17	18.3	57.9
Mar. 1960	30	7.6	63.2	22	17.8	62.2
Apr. 1960	19	9.6	58.9	14	17.8	54.9
May 1960	30	8.7	53.2	19	20.8	50.9
June 1960	30	11.2	54.8	19	22.5	50.8
July 1960	31	11.4	52.8	20	23.0	48.8
Aug. 1960	31	9.9	54.0	24	22.6	47.6
Sept. 1960	30	9.3	59.2	22	20.6	54.4
Average	(8 mo.)	9.6	57.2	(8 mo.)	20.4	53.4

been eminently satisfactory and on occasion have pumped sludges with 27-per cent solids. The only difficulty experienced has been with nuts and bolts from broken screw conveyor shafts which become embedded in the rubber-lined stator and cause damage to the rotor. The sludge concentration tanks continue to function satisfactorily in spite of low volatiles. The monthly averages of daily composited primary and concentrated sludges during the first six months preceding the shutdown of the incinerators and eight months of operation in 1960 following the modification of the incinerators are given in Table IV.

On June 24, 1960, composited concentrated sludge averaged 26.2-per cent total solids for the day. The total solids of concentrated sludge for the month of July 1960 on a composited basis reached a high average of 23.0 per cent. August 1960 fell off slightly to 22.6 per cent solids. Table IV demonstrates the improvement following the elimination of the difficulties with the incinerators. The primary sludge, following resumption of incineration, has been less viscous and has averaged 8.2 per cent greater volatile solids. The concentrated sludge also shows improvement in many respects.

Supernatant liquor has more than met design assumptions. A sludge density meter records concentration of the supernatant immediately to permit accurate control. Withdrawal of supernatant after approximately 6 hr is stopped when the chart indicates 3 per cent. The increase from 0.5 to 3 per cent occurs in a matter of minutes. Supernatant is composited at hourly intervals. Typical averaged analyses of supernatant for the months of July and August 1960 are given in Table V.

Sludge heating has presented no problem except for the difficulty of control of temperatures, which must be done manually. Two of the five heat

TABLE V.—Average Analyses of Supernatant

Month	pH	Alkalinity, as $CaCO_3$ (mg/l)	Susp. Solids (mg/l)	Vol. Susp. Sol. (%)	BOD (mg/l)
July 1960	5.6	1,902	5,640	57.6	6,915
Aug. 1960	5.8	2,065	8,552	61.9	7,241

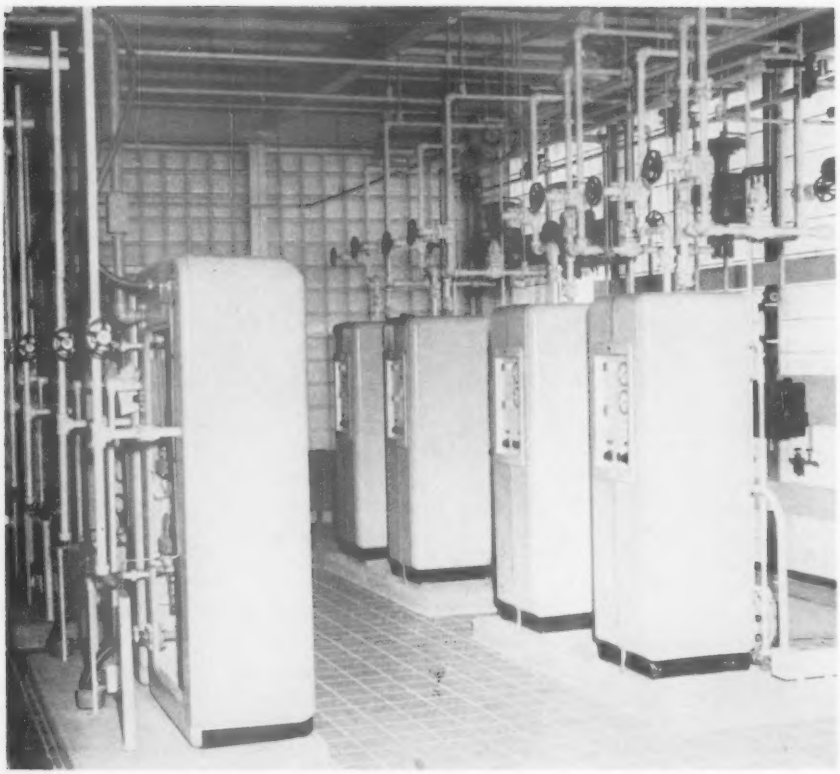

FIGURE 12.—Chlorinators and evaporators in chlorinator room.

exchangers are now arranged to permit heating of effluent flushing water for removal of accumulated grease from the sludge lines.

Chlorination

Chlorination (Figure 12) is applied to the raw sewage ahead of the screens as prechlorination, and in the influent channels of the sedimentation tanks as postchlorination. Experience indicates that prechlorination is more desirable and just as effective as postchlorination in the present circumstances.

Sampling

Automatic sampling of raw sewage ahead of the screens has been abandoned as being too troublesome to maintain. Supernatant is now being returned at this point. All plant sampling is done manually.

Temperature and Odor

As soon as the incinerators were shut down, the Authority engaged in research work to determine the true temperature of deodorization. The consulting engineers made similar tests on primary and concentrated sludges, the primary sludges being obtained from various plants in the vicinity of Boston. Although operating independently with different sludges, both the Authority investigators and the consultants agreed that the true temperature of deodorization of Pittsburgh concentrated sludge is a minimum of 1,425°F and not 1,250°F as was assumed and specified. According to the

laboratory findings, both primary and concentrated sludges at Pittsburgh require a minimum of 1,425°F for deodorization.

The pyrometers to measure temperatures may be located anywhere in the incinerator furnace, but the important point is that gases or vapors must be subjected to temperatures of at least 1,425°F for destruction of sludge odors. The pyrometers in the Pittsburgh plant are located in the vicinity of the inlet end of the preheater where the gases of combustion enter the tubes on the way to the dust arresters and stack. Originally the odoriferous drying vapors were discharged into the furnace at practically the same point. Before the path of the vapors was changed the pyrometers recorded as much as 1,350°F at times, but sludge odors persisted. It was only after the same vapors were discharged into a hotter part of the furnace that sludge odors disappeared. However, sludge odors reappeared in the stack when the pyrometers indicated temperatures below 1,225°F. Temperatures, therefore, at the present location of the pyrometers, are maintained above 1,250°F but not greater than 1,300°F. In other words, the pyrometers in their present location record a relative temperature insofar as deodorizing temperatures are concerned.

Another important factor is contact time. Little has been written about this and nothing specified as far as is known, but laboratory experiments indicate that to destroy sludge odors proper contact time must be made available in addition to sufficient temperature. Subjected to the same deodorizing temperatures, sludges with 0.77-sec contact time produced odors, but when the contact time was increased to 3 sec, sludge odors disappeared.

During the first six months of operation, a number of so-called "industrial perfumes" were tried in the attempt to destroy sludge odors, but without success. A pilot-plant scrubber was tested in the hope that sludge odors would be scrubbed out. The results were inconclusive. In any case, the cost of construction for disposal of the highly acid effluent was deemed prohibitive. A pilot-plant ozone machine was rented for experimentation, and serious consideration was given to the testing of catalytic devices for sludge odor control, but before these devices could be put to test, the revamped incinerator had demonstrated that sludge

TABLE VI.—Shift Operating Personnel

Position	No.
Shift superintendent	1
Guard	1
Incinerator foreman	1
Incinerator operator	2
Incinerator helper	2
Boiler operator	1
Boiler fireman	1
Sludge conc. and heating operator	1
Sludge conc. and heating helper	1
Pump operator	1
Pump helper	1
Rack and grit operator	1
Sedimentation operator	1
Sedimentation helper	1
Blower room operator	1
Chlorination operator	1
General utility man	1
Total per shift	19

TABLE VII.—Distribution of Employees

Personnel	No.
Sewage treatment plant:	
Shift personnel, 4 x 19	76
Truck drivers	2
Sludge engineer	1
Maintenance engineer	1
Maintenance clerk	1
Maintenance mechanics	18
Maintenance laborers	6
Landscapers	2
Storekeeper	1
Assistant storekeeper	1
Total	109
Intercepting sewer system maint.	21
Industrial wastes investigators	8
Laboratory	11
Billing and collecting	36
Engineering	4
Administrative	21
Grand total	210

odors could be eliminated without the employment of auxiliary devices.

Operating Costs

The personnel required per shift for operation of the sewage treatment plant are given in Table VI. The total number of employees, including shift and all other operations, is distributed as given in Table VII. The budget and disbursements for the first eight months of 1960 are given in Table VIII.

Summary

Adjustments and improvements of operations are continuing to the end that maximum efficiencies may result. Concentration of sludge to a degree exceeding design assumptions; the satisfactory characteristics of the supernatant liquor; the successful pumping of concentrated sludge; and the successful destruction of sludge odors by incineration are established facts. It only remains to complete the adjustments to

TABLE VIII.—Budget and Disbursements for First Eight Months of 1960

Item	Budget	Disbursements
Administration, engineering and general	$ 184,000.00	$ 298,150.71*
Collection of sewer service charges	250,666.68	288,665.85
Operation and maintenance of treatment plant		
Labor		
General	98,666.68	66,882.39
Laboratory	106,666.68	71,465.31
Main pumping station	37,333.32	35,772.42
Rack and chlorination building	26,666.68	25,616.39
Grit chambers	29,333.32	32,440.55
Preaeration and sedimentation tanks	34,666.66	27,004.89
Blower plant	18,666.68	16,812.09
Sludge concentration and heating	34,666.66	25,384.86
Sludge incineration	82,666.68	66,154.89
Maintenance	85,333.32	93,755.15
Sub-total	554,666.68	461,288.94
Power	168,000.00	135,578.18
Supplies and miscellaneous		
Chlorine	106,666.66	82,398.00
Coal	88,000.00	38,140.52
Water	18,666.64	43,401.88
Gas	21,333.36	7,363.96
Miscellaneous	26,666.66	68,760.63
Sub-total	261,333.32	240,064.99
Total	984,000.00	836,932.11
Operation and maintenance of intercepting system		
Labor	106,666.66	81,874.69
Power	6,666.68	3,934.52
Supplies and miscellaneous	8,533.32	12,817.75
Total	121,866.66	98,626.96
Insurance	8,000.00	11,314.65
Contingencies	51,466.66	—
Grand total	$1,600,000.00	$1,533,690.28

* Includes $110,950.75 for Social Security, hospitalization benefits, and pension accounts.

TABLE IX.—Operating Results* With One Battery of Sedimentation Tanks

Date	Flow (mgd)	pH	DO (mg/l)	BOD (mg/l)	Susp. Sol. (mg/l)	Vol. Susp. Sol. (%)	Chlorides (mg/l)	Grease (mg/l)	Cl_2 Demand (mg/l)
(*a*) Raw Sewage									
June 1960	139	6.9	0.1	151	243	62.0	58	65	9.5
July 1960	133	6.8	0.0	139	235	60.0	55	49	9.4
Aug. 1960	130	6.9	0.2	153	231	64.7	60	54	11.7
Average	134	6.9	0.1	148	236	62.2	58	58	10.2
(*b*) Effluent									
June 1960	—	6.9	5.1	124	124	61.7	—	48	—
July 1960	—	6.9	4.8	105	92	60.1	—	36	—
Aug. 1960	—	6.9	4.1	103	71	70.6	—	41	—
Average	—	6.9	4.7	111	96	64.1	—	42	—
Removals (per cent)	—	—	—	25	59	—	—	27.5	—

* Not including grit, screenings, and grease ball removals.

the established conventional types of units of the treatment plant to permit full operation and improved efficiencies. In the meantime, operating results with respect to suspended solids and BOD removals are without material technical significance. To report that 25-per cent BOD and 59-per cent suspended solids removals were obtained during a period of three months with one battery of sedimentation tanks in operation, while the other battery was being adjusted, is interesting but not conclusive. Table IX gives some data on operation during this period.

Acknowledgments

The present Board of the Sanitary Authority consists of Edmund S. Ruffin, Jr., Chairman; Julius E. Graf, Vice-Chairman; Richard B. Tucker, Jr., Secretary; John E. Connelly, Treasurer; and David Olbum, Assistant Secretary-Treasurer. The author was Executive Director and Chief Engineer until his retirement on August 31, 1960. Joseph J. Olliffe, formerly Administrative Assistant, became Executive Director on September 1, 1960, and L. M. Gentleman, formerly Deputy Chief Engineer, became Chief Engineer on September 1, 1960. R. A. Lincoln is Construction Engineer; R. J. Moran, General Superintendent; and H. J. Dickman, Maintenance Engineer. R. J. Dougherty, who left the Authority recently, was Chief Construction Engineer and later General Superintendent. Mr. Moran, who succeeded Mr. Dougherty, was for many years Chief Chemist. Mr. Dickman was Resident Engineer during construction of the sewage treatment plant and main pumping station. Metcalf & Eddy, of Boston, have been Consulting Engineers since 1947 and designed the sewage treatment plant and main pumping station and the intercepting sewers along Chartiers Creek and Turtle Creek and in addition thereto the open-cut portions of the Ohio River intercepting sewer. The late Frank L. Flood was partner-in-charge, now succeeded by Edwin B. Cobb. The Authority engineering staff designed the tunnel system and the balance of the open-cut intercepting sewers. Celli-

Flynn, of McKeesport, Pa., were retained by Metcalf & Eddy for reviewing the architectural planning at the plant in regard to materials, colors, and exterior and interior appearances. Philip S. Miller and Associates, of West Orange, N. J., were consulting engineers on problems dealing with tunnel construction; E. D'Appolonia Associates, of Pittsburgh, were consultants on soil problems; and Thompson & Lichtner Co., Inc., of Boston, represented by Miles N. Clair, were consultants on concrete problems and concrete pipe.

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MEETINGS OF INTEREST

July 16–21 **Summer Training Institute,** Rutgers—The State University, New Brunswick, N. J. Courses in Air Pollution, Radiological Health, and Water Quality Management. Conducted by the staff of the Public Health Service's Robert A. Taft Sanitary Engineering Center. S. C. Martin, U. S. Public Health Service, 42 Broadway, New York 4.

July 24–28 **Recent Developments in Water Bacteriology,** Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

Aug. 20–25 **Annual School for Waterworks, Wastewater, and Industrial Wastes Personnel,** Virginia Polytechnic Institute, Blacksburg, Va. Prof. W. A. Parsons, Sanitary Engineering, Holden Hall, VPI, Blacksburg.

Sept. 3–8 **American Chemical Society,** 140th National Meeting, Chicago, Ill. American Chemical Society, 1155 16th St., N. W., Washington 6, D. C.

Sept. 11–15 **Instrument Society of America,** Memorial Sports Arena, Los Angeles, Calif.

Sept. 11–22 **Basic Radiological Health,** Division of Radiological Health, Public Health Service, Las Vegas, Nev. Chief, Training Program, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio, or to a PHS Regional Office Director.

Sept. 24–27 **American Institute of Chemical Engineers,** 45th Annual Meeting, Lake Placid Club, Lake Placid, N. Y.

TIPS AND QUIPS

Efficiency Study

In the research race with Russia, one good secretary is worth at least two good scientists, a Canadian expert reports.

Robert Sommer of the Saskatchewan Hospital, Weyburn, Canada, observes: "It is axiomatic that a lab can produce only as fast as its secretary can type. The lab with one scientist and four secretaries is in a more favorable position than the lab with four scientists and one secretary.

"In the latter case, the scientist will spend most of his day peering over the secretary's shoulder seeing whether she is showing favoritism to his three colleagues. There will be intrigues and quarrels to get letters typed, income tax forms filled out, and lead pencils requisitioned. Realistically there is no motivation for the scientist to write if there is no one to type for him.

"In the lab with one scientist and four secretaries our man is in constant turmoil to keep his assistants busy. He feels he must produce so that his harem looks busy. If they start bringing in knitting and learning bridge, his superiors will become suspicious."

Sommers formulates the following "law" for the scientific output of any research laboratory:

$$\text{Productivity} = \frac{\text{number of secretaries} \times \text{average typing speed}}{\text{number of scientists}}$$

"One interesting feature of this equation," he notes, "is that when the number of scientists becomes zero, productivity becomes infinite.

"This is probably true, but has never been tested empirically."

Suggesting how this might be researched, Sommer adds, "People have discussed the question of whether a monkey hitting keys at random would ever compose a Shakespearean sonnet. However, this is setting an overly difficult task for the average monkey. If we had asked that our animal type a scientific law, I am sure that he could manage it without too much trouble.

"For example, if a monkey were to punch four keys at random over a long period, he would certainly hit upon $E = mc^2$ in less time than it took Einstein to reach it. Actually the odds of our monkey hitting it on the first try are only 42^4.

"If a monkey can do this, we should certainly expect more from our stenos, some of whom can type seventy words a minute. Think of the scientific laws that could be produced if four secretaries typed random letters at top speed. Some readers may feel that the current year's scientific output bears some resemblance to this, but I believe that a formal experiment would still be worthwhile."

This Cleaner Does Everything

In the new product market is a push-button cleanser that can banish bathtub ring, clean enamel, porcelain, and metal surfaces with a minimum of rubbing. The cleanser, a grease- and dirt-dissolving foam, is reported to require little hand scrubbing because of its quick detergent action.

We thought all this was done by a three-letter product beginning with "D" and ending with "Z."

Caltech's New Facilities

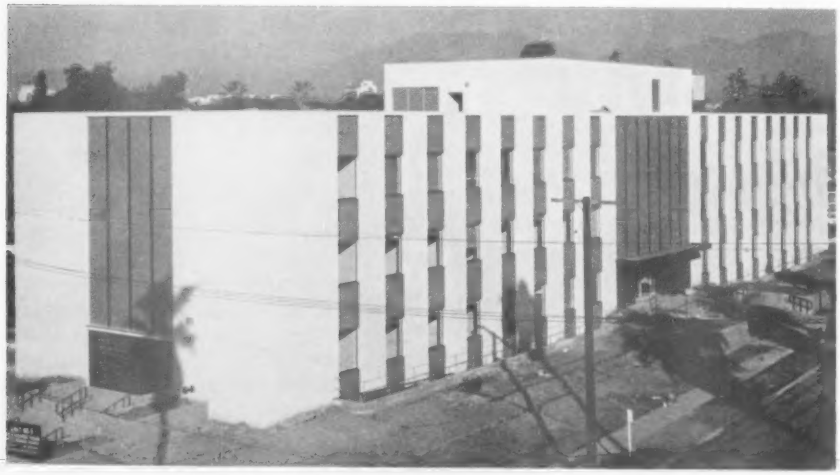
Jack McKee sends along a photo of the new W. M. Keck Engineering Laboratories at the California Institute of Technology in Pasadena. This is part of the Environmental Health Engineering program and was completed late in 1960.

Of the five floors (totaling 66,000 sq ft of gross area) in the red-paneled, buff-colored concrete building, three are used for sanitary engineering, hydraulics, and water resources.

The future is indeed brightened by this example of institutional awareness of the need for training facilities to keep abreast of water problems.

tion utilizes simple, straightforward writing to get to the heart of a subject. Each issue deals with one subject, and after reading it one realizes that if proper preparation is made and if words are carefully chosen, a great deal can be said in four short pages. For instance, the September 1960 Notes discussed "Oxygen Demand Tests for Effluents." Others have covered such subjects as septic tanks, sampling, continuous recording of DO, sulfates in concrete sewers, trickling filters, wastewater and fish, anaerobic digestion of industrial wastes, and treatment of electroplating wastes.

At the risk of seriously affecting the



Caltech's new W. M. Keck Engineering Laboratories.

Notes on Water Pollution

We have been on the enthusiastic receiving end of an excellent little publication which many of the Journal readers would find most helpful in their daily work. It is titled "Notes on Water Pollution" and is produced as a part of the Department of Scientific and Industrial Research in England.

In a four-page leaflet this publication utilizes simple, straightforward writing to get to the heart of a subject. Each issue deals with one subject, and after reading it one realizes that if proper preparation is made and if words are carefully chosen, a great deal can be said in four short pages. For instance, the September 1960 Notes discussed "Oxygen Demand Tests for Effluents." Others have covered such subjects as septic tanks, sampling, continuous recording of DO, sulfates in concrete sewers, trickling filters, wastewater and fish, anaerobic digestion of industrial wastes, and treatment of electroplating wastes.

At the risk of seriously affecting the print order, we urge readers to request copies of "Notes." Address the Director, Water Pollution Research Laboratory, Elder Way, Stevenage, Herts., England.

No man need surrender any real conviction in order to be tolerant; all he needs to do is admit the right of other men to hold a differing opinion.

DON'T MISS MILWAUKEE!

An Editorial

During the second week in October, the spotlight of the wastewater field moves to Milwaukee, Wisconsin. The Milwaukee Auditorium-Arena will house the technical sessions and exhibits of the Federation's Annual Meeting from October 8 through 12.

The Host Association, the Central States Sewage and Industrial Wastes Association, has big plans for you! Such plans could be expected only from one of the oldest Member Associations in the Federation in a location where industry is the lifeblood of the community and where much of the developmental work in sewage treatment was done.

All indications are for a successful meeting in every respect. George E. Symons, Chairman, and his Publications and Program Committee have prepared the most diversified program ever assembled for a Federation meeting. With 15 technical sessions and 51 papers, everyone concerned with water pollution control through the proper collection and treatment of sewage and industrial wastes will find offerings of great interest and technical value.

The manufacturers will exhibit the finest in equipment and processes. Manufacturers already familiar to the field and new exhibitors will show both established products and the latest, thought-provoking new ideas. With abundant space exhibitors will have every reason to make the best possible showing.

The Local Arrangements Committee, with W. N. Konrad as chairman, has plans to make your stay in Milwaukee most enjoyable. While the Hotel Schroeder will be headquarters, the Committee will have "Housing Bureau" services for additional rooms allotted in the Wisconsin Hotel, Plankinton House, and Milwaukee Inn.

Full entertainment will be available, and a special program awaits the ladies.

Milwaukee, the home of the Braves and other well-known products, offers many entertainment attractions. Most likely the World Series will extend into the meeting week and, of course, Milwaukee could be the site of the series.

Also of exceptional interest will be the inspection trip to the Milwaukee Sewage Treatment Plant. Virtually the "granddaddy" of large activated plants in the United States, it has been producing genuine Milorganite since 1925! Visitors will see its full operation.

Wednesday, October 11, has been designated "Industry Day," a feature of great popularity at the 1960 meeting. Because of the strong interests of the pulp and paper industry in Wisconsin, co-sponsors for the industrial wastes sessions include the National Council for Stream Improvement, the Institute of Paper Chemistry, the Sulphite Pulp Manufacturers' Research League, and the Northwestern Pulp and Paper Association. In addition to Industry Day, papers of interest to industry people will be given throughout the meeting. On October 10 and 11 four half-day sessions are scheduled wholly devoted to industry topics.

Make your plans now. Don't miss Milwaukee!

R. E. F.

REVIEWS AND ABSTRACTS

The Discharge of Effluents into Inland and Tidal Waters. By B. F. Holden. *Jour. Inst. Munic. Engr.* (Brit.), **87**, 8, 283 (1960).

This article begins with the controversial statement that, "The disposal of trade and sewage wastes by dilution with a sufficient quantity of clean water is the most effective and least offensive method of purification." This is followed by a brief survey of the legislation and Royal Commission recommendations governing the disposal of effluents. Then the author returns to his original statement and the remainder of the article attempts to justify his remarks, solely in respect to tidal waters. He examines the objections to the disposal of raw sewage and sewage effluents into tidal waters, on the grounds of the public health risk and amenity. In considering the former the author points out the lack of any evidence to show that there is danger of disease being transmitted in sewage polluted tidal waters, stressing the opinion of the Medical Research Council, as set out in their Memorandum No. 37. (In this section there appears to be some confusion between bacteria and viruses.) On the grounds of amenity, the author considers that, if sufficient care is taken in locating the outfall, this method involves less nuisance than conventional sewage treatment plants, which fail to treat stormwater and whose offensive sludge drying beds produce large quantities of unsalable sludge.

A. James

Laboratory Experiments with Biological Removal of Nitrogen from Waste Water in the Form of Nitrogen Gas. By G. Bringmann, R. Kühn, and B. Wagner. *Gesundh.-Ing.*, **80**, 364 (1959).

Laboratory experiments have shown that nitrogen compounds present in wastewaters may be removed from the wastewater in the form of nitrogen gas by applying biological sewage treatment processes. The first stage of the process includes the oxidation of all ammoniacal nitrogen present in the wastewater to nitrites and nitrates. This process of nitrification can be achieved by any known aerobic biological process of sewage treatment. In the second stage, denitrification of the nitrites and nitrates is effected by an anaerobic process; viz., by adding suitable oxidizable substances as reducing agent such as domestic sewage to the oxidized wastewater. Certain types of bacteria present in sewage will make use of the oxygen available from the nitrites and nitrates and thus will liberate nitrogen gas or nitrogen dioxide.

Supernatant liquor drawn off from a sludge digestion tank of a municipal sewage treatment works could be treated successfully in this way. About 77 per cent of the ammoniacal nitrogen (975 mg/l) present in the supernatant liquor was removed in the form of nitrogen gas.

W. J. Müller

Development and Operation of Mechanical Contact Aeration Plants. By H. Hartmann. *Gas- u. Wasserfach*, **101**, 12, 281 (1960).

In a new process of mechanical contact aeration, the surface area exposed to sewage to be purified is composed of circular plates half submerged into the liquid. The plates are set vertically about 7/8 in. apart. Aeration of the bacterial growth on the plates is effected by rotating the plates in such a way that the bacterial growth is exposed to air and sewage alternately. The speed of rotation is about 2 to 3 rpm.

In pilot plants using mechanical contact aeration it was possible to produce effluents which were similar in quality to those normally obtained by the application of conventional biological sewage treatment processes.

W. J. Müller

Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Water Pollution Control Federation, 4435 Wisconsin Ave., Washington 16, D. C.

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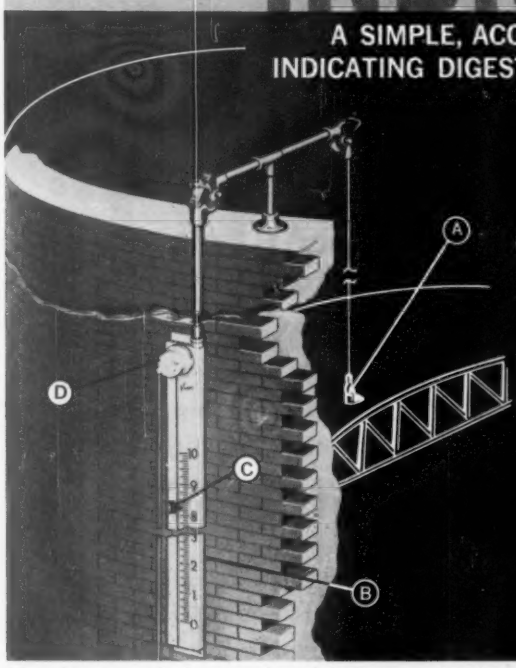

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Comminutors (*also see* Shredders and Grinders)
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American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Infilco Inc.
Jeffrey Mfg. Co.
Smith & Loveless
Walker Process Equipment Inc.
Worthington Corp.

Compressors
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Worthington Corp.
Yeomans Brothers Co.

Computers
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.

Concentrators (*see* Sludge Concentrators)

Concrete
Portland Cement Assn.

Concrete Pipe Products
American Concrete Pressure Pipe Assn.
American-Marietta Co.
Gray Concrete Pipe Co., Inc.
Industrial Materials Co.
Lock Joint Pipe Co.
National Sewer Pipe Ltd. (Canada)
Portland Cement Assn.
Price Brothers Co.

Construction Equipment
Chain Belt Co.
Eimco Corp.
Worthington Corp.

PROCEEDINGS OF MEMBER ASSOCIATIONS

CANADIAN INSTITUTE ON SEWAGE AND SANITATION

The 27th Annual Convention of the Canadian Institute on Sewage and Sanitation was held at the Sheraton Brock Hotel, Niagara Falls, Ont., Oct. 23–26, 1960. The registration total was 619, of which 169 were ladies.

The technical program, on Monday morning, was devoted to guided discussions on municipal sanitary problems. Past President of the Federation, Mark D. Hollis, was the formal luncheon speaker. His subject was "Water Resources." The Monday afternoon session was divided between water pollution and air pollution.

Tuesday's program included the business meeting in the morning with the remainder of the day devoted to technical papers and a two-hour question and answer period.

The Annual Banquet on Tuesday evening had an attendance of 454. On this occasion, the Bedell Award was presented to A. Valentine Delaporte, Oakville, Ont., for his outstanding service to the Canadian Institute; the Hatfield Award winner was William Hardy, Woodstock, Ont., for his outstanding treatment plant operation and reporting.

Among the papers presented were:

"Clean Waters for New England," by Joseph C. Knox, New England In-

(*Continued on page 379a*)

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Filtration Equipment Corp.
Industrial Materials Co.
Snow Gates & Valves, Inc.
Webster Mfg., Inc.

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Westinghouse Electric Corp.
Worthington Corp.

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Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

terstate Water Pollution Control Commission, Boston, Mass.

"A Canadian Program for Pollution Control," by A. L. Van Luven, H. E. McKeen and Co., Ltd., Lachine, Que.

"Design and Construction of the Brantford Sewage Treatment Plant," by Harry G. Richards, City Engineer, Brantford, Ont., and D. B. Redfern, Consulting Engineer, Toronto, Ont.

"Modern Practice in Sewer Rates," by R. K. Brown, Deputy Commissioner of Roads, Scarborough Township, Ont.

A guided discussion on sewer maintenance with Lucien L'Allier, Director of Public Works, Montreal, Que., as Chairman.

"Disposal of Solid Industrial Wastes," by D. P. Scott, Deputy Commissioner of Works, Metropolitan Toronto, Ont.

"Modern Practices in Sludge Dewatering and Disposal," by James W. MacLaren, Consulting Engineer, Toronto, Ont.

"Municipal Control Over Industrial Wastes to Sewers," by F. A. Voege, A. J. Harris, and R. H. Millest, Ontario Water Resources Commission, Toronto, Ont.

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NEBRASKA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 9th Annual Meeting of the Nebraska Sewage and Industrial Wastes Association was held at the Castle Hotel, Omaha, Nebr., Nov. 3–4, 1960.

(*Continued on page 381a*)

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Cast Iron Pipe Research Assn.
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Industrial Materials Co.
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Robinson Clay Product Co.

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National Water Main Cleaning Co.
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Koppers Co., Inc.
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American-Marietta Co.
American Pipe & Construction Co.
Gray Concrete Pipe Co., Inc.
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National Sewer Pipe Ltd. (Canada)
Portland Cement Assn.
Price Brothers Co.

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Sonoco Products Co.

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Cast Iron Pipe Research Assn.
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Pipe, Repairs
Centriline Corp.
Smith-Blair, Inc.

Pipe, Steel
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Armco Drainage & Metal Products, Inc.
Keasbey & Mattison Co.
A. O. Smith Corp.

Plastic Pipe Products
Amercoat Corp.
Evanite Plastic Co.
Keasbey & Mattison Co.

Publications
American City Magazine
Engineering News-Record
Liverpool University Press (England)
Public Works Magazine
Wastes Engineering Magazine
Water & Sewage Works

Pump Controls
Builders-Providence Div., B-I-F Industries
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Fischer & Porter Co.
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Penn Instruments Div., Penn Meter Co.
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Westinghouse Electric Corp.
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The Thursday afternoon session featured a "Discussion of the Papillion Creek Plant," by Paul Bolton, Sanitary Engineer, Henningson, Durham and Richardson, Omaha. This was followed by a field trip to the new Omaha Papillion Creek Sewage Treatment Plant, which is a unique installation.

The Annual Section Dinner on Thursday was followed by the business meeting.

Federation President Ray E. Lawrence was the speaker at the Association Luncheon on Friday.

The Annual Banquet was the highlight of the meeting. Presentation of awards was followed by a talk on "Coordinated Clean-Up" by a representative of the United States Public Health Service.

Papers of interest were:

"The Coil Filter," by Oliver Barklage, President, Oliver Barklage Co., Omaha.

"The Flash Dryer," by Claude Leet, Product Manager, Combustion Engineering, Inc., Chicago, Ill.

"Lubrication of Equipment in the Sewage Treatment Plant," by Harold Hemphill, Industrial Representative, Socony Mobil Oil Co., Hastings.

"Sampling and Testing Within the Sewage Treatment Plant," by Bruce Meier, Chief Sanitary Engineer, Kirkham, Michael and Associates, Omaha.

Report from the Division of Sanitation, State Department of Health, by T. A. Filipi, Lincoln.

"Financing of Sewerage Works and Treatment Facilities," by Leonard Lawrence, President, Robert E. Schweser Co., Omaha.

"Studies Necessary for a Preliminary Report on a Sewage Treatment Plant," by Paul Mousel, Mousel and Wright, Consulting Engineers, McCook.

"The Development of the Sanitary Engineer," by Ed Pershe, Department of Civil Engineering, University of Nebraska, Lincoln.

(*Continued on page 384a*)

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Link-Belt Co.
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Worthington Corp.

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Preload Co., Inc.
A. O. Smith Corp.
Stebbins Engr. & Mfg. Co.

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General Electric Co.
Westinghouse Electric Corp.

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The 1960 Spring Meeting of the Swedish Association for Water Hygiene was held in Helsinki, Finland, May 27–29, 1960. About 250 members attended the three-day meeting, with 50 ladies present as guests.

The meeting opened with an address by Walter Starck, City Engineer, Helsinki. The following papers were presented at the technical session:

"Water Problems of the Pulp and Paper Industries in Finland," by Harald Tötterman, Doctor of Philosophy, Central Laboratory, Helsinki.

"Problems with the Water Supply of Helsinki from the Limnological Point of View," by Ilpo Kangas, Water Works, Helsinki.

"Purification of Sewage in Helsinki," by Harry Cajander, Civil Engineer, Sewage Works, Helsinki.

"The International Question Dealing with Water Protection Under the Water and Sea Laws," by Eero Manner, Attorney General, Helsinki.

The days following were devoted to excursions to different water and sewage works in the district of Helsinki and Åbo.

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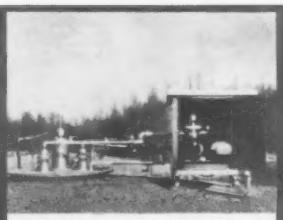

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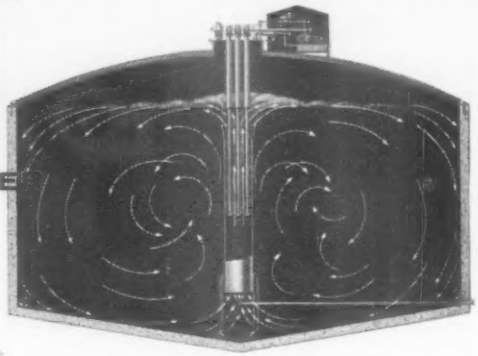

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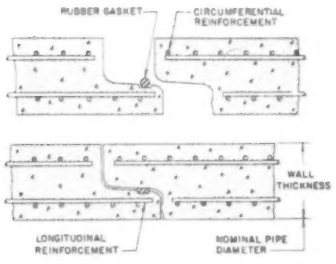

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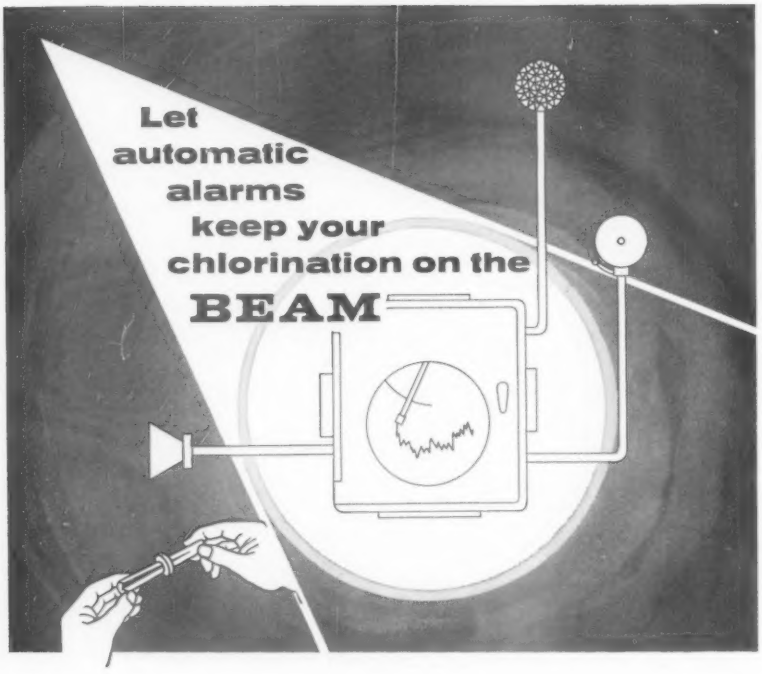

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